Assessment of techniques for measuring hand pressures in mock deliveries on a mannequin

by

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Assessment of techniques for measuring hand pressures in mock deliveries on a mannequin

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Abstract

Shoulder dystocia is a serious obstetric emergency. Brachial plexus injuries can be caused by hyperextension of the neck or misalignment of the fetal head during traction. To address knowledge gaps relating to clinician applied forces associated with deliveries, this study analyzed hand pressures applied by obstetricians in mock deliveries and suggests improvements for pressure-sensing gloves. The subjects were obstetricians, both residents and staff, recruited from the University of Kansas Hospital. A Laerdal PROMPT Birthing Simulator was used for the mock deliveries. The experimental design involved two pressure measurement strategies. Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) with twelve pressure sensors for each hand provided pressure measurements with time. Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] recorded areas where pressure was applied.

The two measurement techniques compared well in capturing the spatial distribution of pressures across the hands. Both indicated pressure was exerted primarily with the middle, index, and ring fingers. Pressures due to the thumb and the palm were significantly smaller. Nonzero average pressures produced by the left hand were higher than the right but not significantly so. The pressure-film data indicated that pressures applied by resident and staff subgroups were comparable, except for the left hand where staff members applied significantly higher pressure with the little finger.

With the glove sensors, there were three conditions: downward traction only, excessive force, which simulated conditions where damage could occur, and full delivery. The downward traction only, excessive force, and full delivery conditions had similar results with few

significant differences. The residents and staff had few significant differences for these conditions between each other and between the conditions. The staff may have been more adept at using all the regions of their hands efficiently to apply balanced pressures.

The glove sensors covered a range from 0 to 20 psi (0 to 0.14 MPa). If pressures exceeded the maximum of the range, the accuracy of the data decreased. This suggested that perhaps the sensor range should be improved in newer designs. Other important design changes could include increasing the numbers of sensors.

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I would like to thank Dr. Sara Wilson for her patience, support, and guidance with this study. She is always helpful, positive, and realistic. Next, I would like to thank Dr. Weiner for his advice and time and the use of his equipment and facilities. I would also like to acknowledge Dr. Kieweg for her assistance and Linda Samuelson, RN for her time, help, and the use of her facilities at the Kansas University Medical Center. I acknowledge the members of my examination committee, Dr. Sarah Kieweg and Dr. Carl Weiner for their review of the work.

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Chapter One: Introduction

Significance

The term dystocia refers to difficulty experienced during childbirth. Shoulder dystocia, which is the focus of this thesis, occurs when the infant's anterior shoulder, relative to the mother, lodges against the pubic symphysis following the delivery of the head [1]. Typically, it is considered to be a serious obstetric emergency. Because loss of oxygen and infant death can occur when delivery becomes delayed, larger than normal and off-axis traction forces may be applied to the infant's head to free the trapped shoulder so that delivery may proceed, even though axial forces are less likely to cause damage [2]. This force could cause injuries of varying severity, such as humeral fracture, clavicle fracture, and brachial plexus injury [1].

While upsetting to the parents, clavicle and humeral fractures are less severe injuries and always heal during the neonatal period [1]. Much more problematic is brachial plexus injury, which involves stretching or even rupturing of axons or surrounding sheaths in nerves controlling the muscles of the arm. When nerves are ruptured or avulsed (i.e., torn off), the injury may be permanent, even after neurosurgery [1]. Anoxic injury is the most serious complication associated with shoulder dystocia. It is caused by interruption of cord blood flow and may lead to circulation problems and even death. The risk of fatality with anoxic injury pressures obstetricians to complete delivery quickly, even if it means causing clavicle and/or humeral fractures as collateral damage. Perinatal morality occurs in about 6.2% of all shoulder dystocia cases [3]. Thus, shoulder dystocia is a dangerous complication that creates a risk of neonatal death or profound and lasting impairment.

Fortunately, shoulder dystocia is rare, encountered in 0.6% to 1.4% of all deliveries [4]. However, other studies suggest a range from 3.3% to 7 % of full-term deliveries, which Gurewitsch and Allen [1] suggest is more accurate. Because shoulder dystocia is difficult to predict and prevent, the most serious concern is that this emergency usually occurs without warning, leaving little time to prepare.

The only guaranteed method of preventing shoulder dystocia is elective cesarean section, which may result in many other complications for both mother and child and can still lead to brachial plexus injuries. Thus, a cesarean section is not considered an efficient and monetarily effective method of preventing shoulder dystocia. It is estimated that preventing one permanent brachial plexus injury due to shoulder dystocia would cause more than 3500 unnecessary cesarean sections to be performed and that the extra cost would be nearly $9 million [1]. Despite the low likelihood of actually preventing shoulder dystocia via cesarean section, many obstetricians feel pressured to offer cesarean sections to women with suspected large or macrosomic fetuses, with birth weights equal to or in excess of 4000 g, in order to avoid lawsuits resulting from complications due to shoulder dystocia [5].

Another possibility for reducing the complications of shoulder dystocia is dealing with them prenatally [1]. Risk factors for shoulder dystocia are known. An Israeli study indicated that the independent risk factors for shoulder dystocia are fetal macrosomia, failure of labor to progress during the second stage, diabetes mellitus, and advanced maternal age [3]. From a review of previous studies, Gurewitsch and Allen [1] identified baseline maternal obesity, excessive weight gain during gestation, maternal diabetes, and postdatism (i.e., post-term gestation) as risk factors. However, these are just risk factors and are not predictive of the outcome for a specific patient. From a public health perspective, intervention in controlling fetal and excessive maternal weight gain as well as managing diabetes should reduce the problem of shoulder dystocia [1].

Shoulder dystocia is one of the four most prevalent causes of medical litigation in obstetrics and gynecology, the others being fetal distress, uterine rupture caused by a vaginal birth after a previous cesarean section, and misdiagnosis of breast cancer [5]. Injuries attributed to shoulder dystocia are the cause of around 40% of all obstetric malpractice claims [6], which is another reason that obstetricians dread this condition. More than half of medical malpractice suits are motivated not by actual medical malpractice but by poor outcomes [5]. Indeed, actual malpractice may have little bearing on the outcome of a lawsuit. A Harvard study showed that a patient's chances of winning a lawsuit depended mostly upon the severity of the outcome, independent of the quality of the care offered [7]. This study also showed that medical error rates are not reduced by lawsuits, indicating that lawsuits are not an effective way to improve medical care, perhaps because lawsuits are used indiscriminately in a shotgun approach.

Only a small minority of malpractice lawsuits are actually filed by patients who received substandard care [7]. Brachial plexus injury, which can cause serious nerve disorders that may be transient or permanent, is commonly attributed to shoulder dystocia and is often claimed to be caused by the birth assistant's malpractice. However, about half of the cases of brachial plexus injury do not occur with clinically diagnosed shoulder dystocia but do occur in average or small sized infants [8]. Brachial plexus injury may occur during spontaneous delivery or cesarean section [8]. 39% of brachial plexus injuries, including some severe cases, involve the posterior shoulder. This shoulder is not trapped during shoulder dystocia and thus should not be stretched and injured by birth assistants if the current theories of how brachial plexus injury occurs are correct [8].

Study Goals and Objectives

The problems associated with shoulder dystocia are thought to be reasonably well understood with tested algorithms for dealing with the delivery room emergencies, though there is some debate on the specifics, such as the best position for the mother. Yet, there are important gaps in specific quantitative knowledge relating to traction forces of the physician and the orientations of these forces during deliveries. Moreover, the reductions in forces through delivery maneuvers are also not well known. The overall goal of this project, including this study, is to contribute to knowledge of the force-thresholds capable of creating brachial plexus injuries and how these forces might be generated, though this study is only concerning itself with pressure. Specific objectives of the project are to determine the traction forces that might be applied by obstetricians and to validate the pressure-sensing gloves and establish their efficacy in research and teaching.

This study is focused on gathering preliminary hand pressure data, on validating that the pressure sensors of the gloves are correctly placed, and on generating recommendations to create an improved version of the gloves for future segments of the project. If the pressure sensors of the gloves are not correctly placed, this study seeks to determine where the pressure sensors should be placed for proper data collection coverage. This study will also determine if the pressure data gathered often peaks over the maximum pressure threshold of the sensors so as to be able to make a recommendation for the maximum pressure threshold of the sensors for the next generation of gloves.

Chapter Two: Background

Mechanics of How Shoulder Dystocia Occurs

Shoulder dystocia disrupts a normal vaginal delivery when the anterior fetal shoulder impacts the mother's pubic bone or symphysis pubis, following delivery of the fetal head (Figure 1). Most commonly, the fetal head is larger than the shoulder and chest. Thus, once the head is delivered, the shoulders should pass through the vaginal canal relatively easily. However, in a few cases, the shoulders are larger, increasing the risk of shoulder dystocia. A later section in this chapter will review studies that identify factors contributing to the risk of a problem birth.

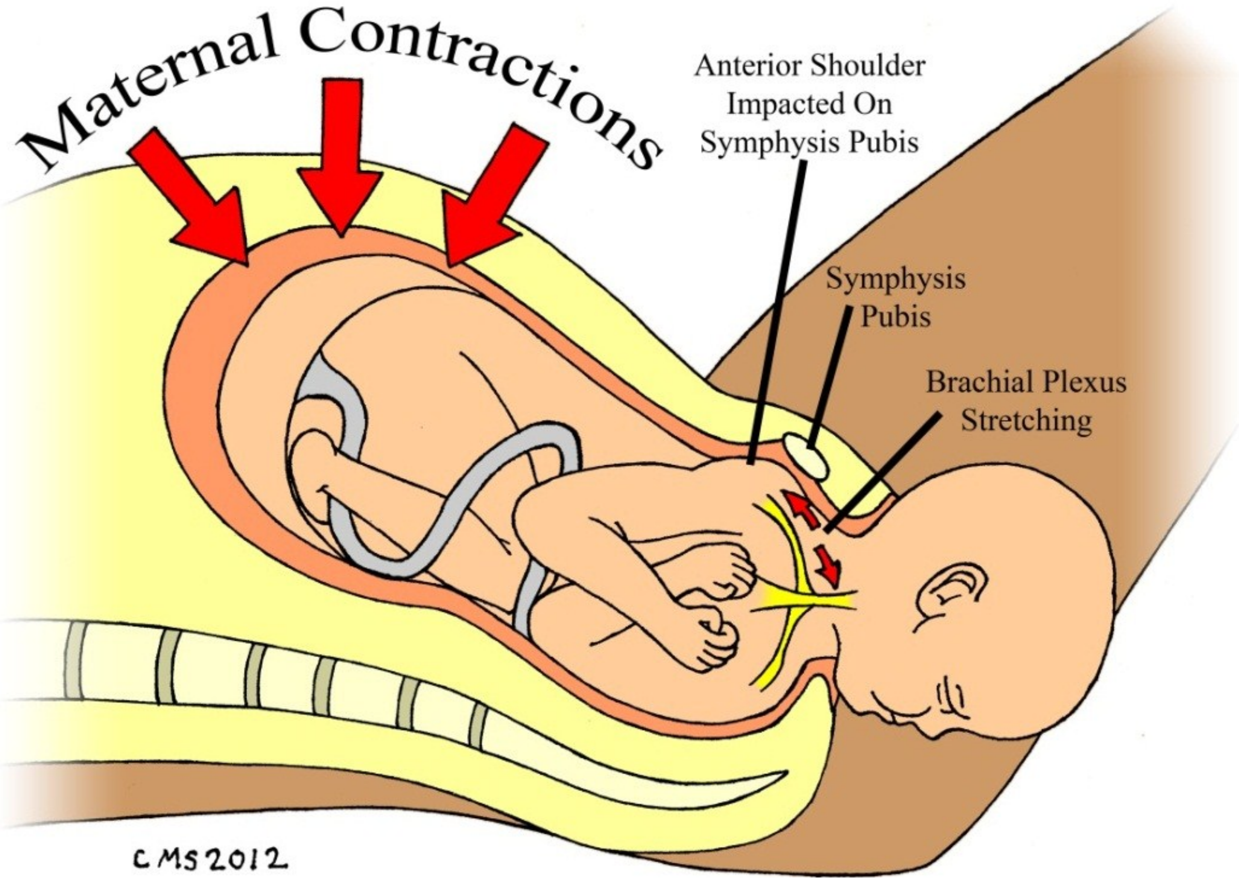

Figure 1: A birth complicated by shoulder dystocia occurs when the anterior shoulder of the fetus becomes trapped behind the symphysis pubis. One of the dangers of this complication is stretching of the brachial plexus.

Injuries Related to Shoulder Dystocia

Shoulder dystocia is a potentially life-threatening obstetric emergency that requires fast action on the part of the clinician. Strategies for coping with shoulder dystocia include, but are not limited to, simply applying larger forces than usual to the fetal head to free the shoulder that is stuck or various delivery maneuvers that may be applied to the mother, the infant, or both. However, applying large forces to the fetal head is considered improper technique because it has poorer outcomes than other options [2]. Rotational maneuvers are preferred. Because time is of the essence, inaction is considered more serious than causing some amount of birth trauma related to heavy traction forces or off-axis forces to the fetus to free the shoulder, though axial forces are considered to be less damaging [2].

Chapter 1 identified the types of injuries caused by these larger forces. Clavicle and humeral fractures are considered to be less severe injuries and always heal during the neonatal period [1]. Much more problematic is brachial plexus injury, which involves injuries to the nerves of the brachial plexus. Figure 2 shows the nerves originating from the segments C5, C6, C7, C8, and T1 of the spinal cord. These nerves control muscles in the arm, wrist, and hand (Figure 3). The upper trunk comprises nerves from C5 and C6, the middle trunk is a trial of undivided fibers from C7, and the lowermost trunk comprises nerves originating from C8 and T1 as shown in Figure 4.

Injuries to the brachial plexus are thought to be related to forceful stretching caused by hyperextension of the neck. The injuries range in severity from transient upper trunk injuries that resolve themselves in days to months to more serious injuries when nerves are ruptured or avulsed (i.e., torn off). These injuries may end up being permanent even after neurosurgery [2].

Examples of mechanical stretch injuries are shown in Figure 4 and include Erb's palsy, which is associated with damage to the upper roots (C5-C6), and Klumpke's palsy, which involves injuries to the middle and lower trunks, C7, C8, and T1. Erb's palsy affects the shoulder and elbow; Klumpke's palsy affects the elbow, forearm, and hand. Other injuries could involve all of the roots [2].

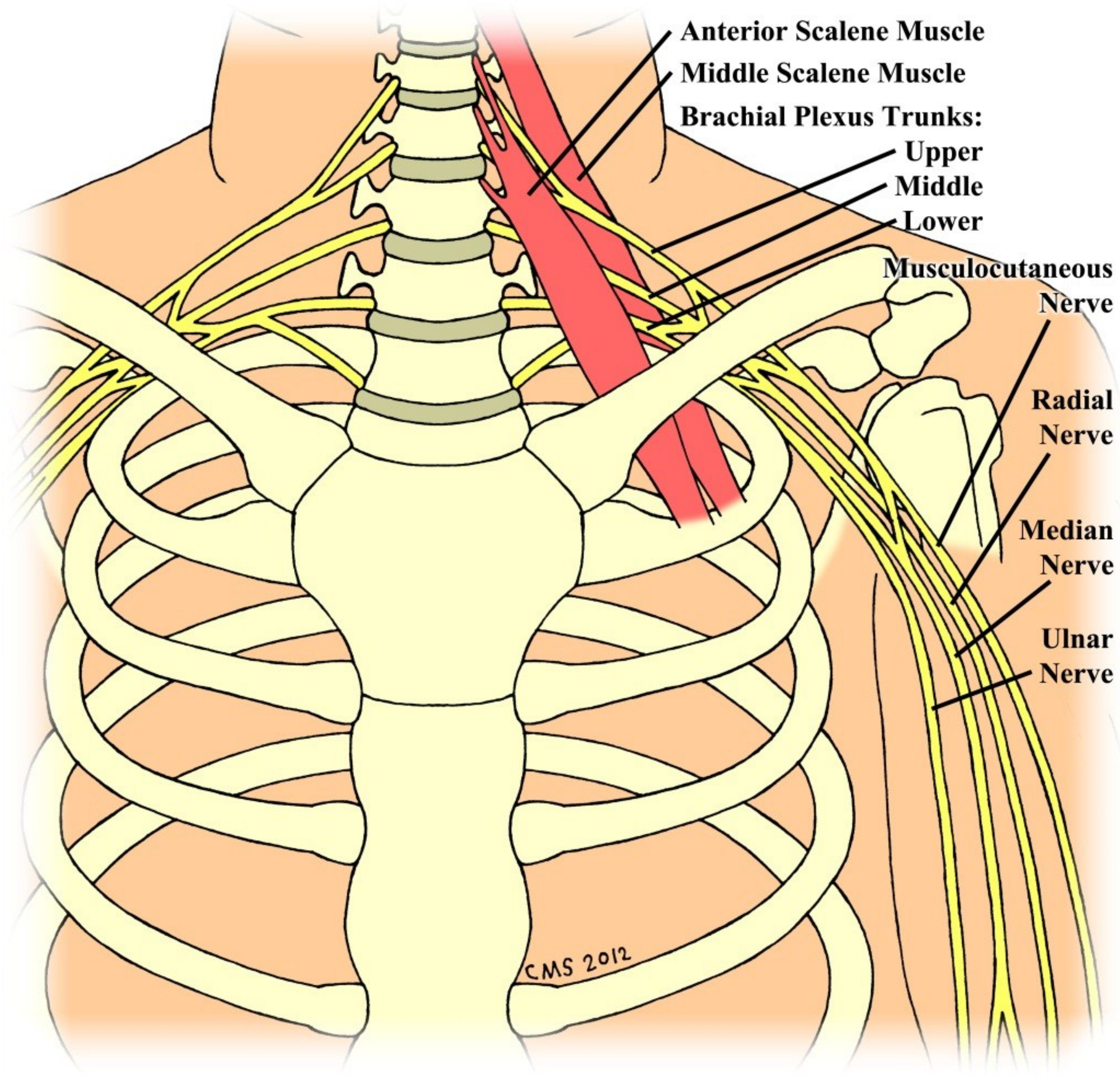

Figure 2: Brachial plexus showing upper, middle, and lower trunks.

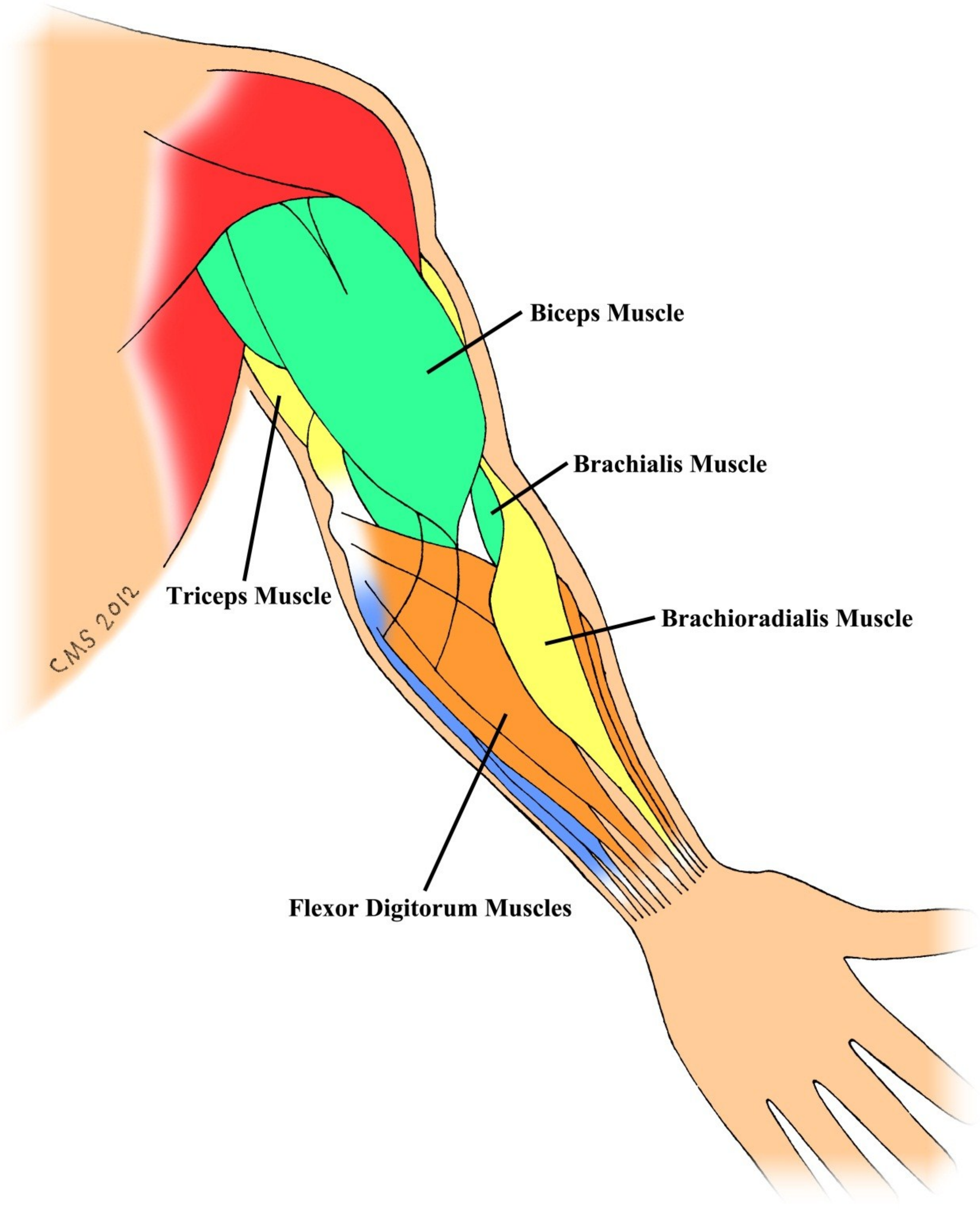

Figure 3: Muscles in the arm controlled through the brachial plexus.

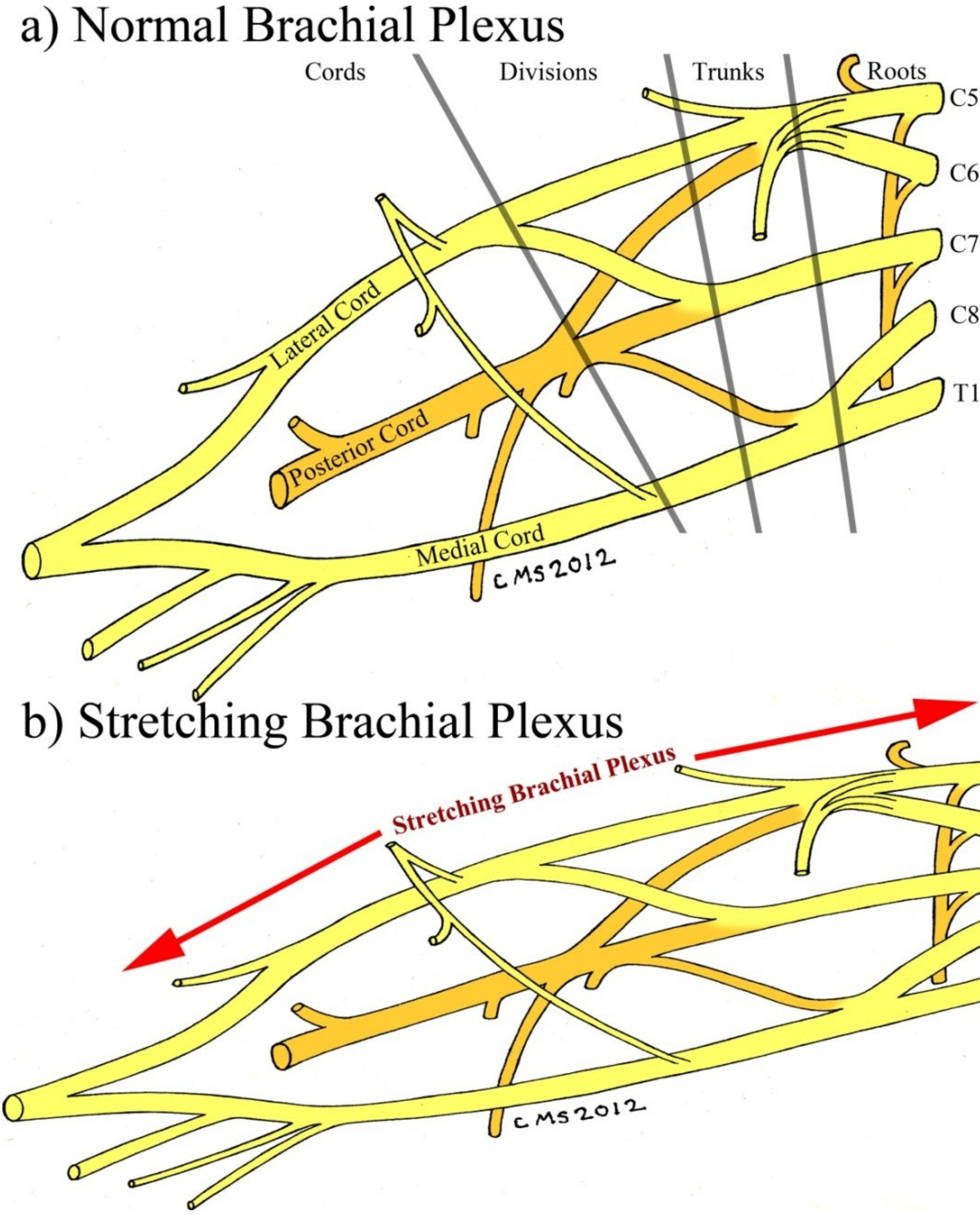

Figure 4: Brachial plexus and location of injuries giving rise to Erb’s and Klumpke’s palsies.

Causes of Injuries Related to Shoulder Dystocia Deliveries

Several studies have examined the causes of brachial plexus injury. Metaizeau et al. [9] showed with cadaveric work that serious nerve damage occurred with laterally applied (relative to fetal spine) traction of 44 pounds. 88 pounds of lateral traction is needed to rupture or avulse middle and lower roots. A large prospective study by Mollberg et al. [10] found that the number of damaged roots was proportional to the force used. The limited previous work suggests that injury during shoulder dystocia is minimized by traction up to 20 pounds preferentially directed axially (not laterally). Moreover, it is important to confirm appropriate head and shoulder alignment to prevent unusual rotation of the head, contributing to avulsions [1]. In general, however, the number of studies providing quantitative information on the pounds of traction associated with brachial plexus injury appears limited. Also, cadavers often have different, sometimes lower material properties than live humans. As such, cadavers often produce inconsistent results. Infant cadavers can also be difficult to obtain.

Risk Factors Associated with Shoulder Dystocia

Possibilities exist for influencing the risk of shoulder dystocia during the antenatal period (i.e., before the birth) and reducing the risk the complications during birth (intrapartum period) [1]. This section provides background on the risk factors for shoulder dystocia and the possibilities for antenatal reduction of risk through screening and intervention. The next section examines possibilities for intrapartum management of shoulder dystocia to reduce the risk of brachial plexus injury.

The commonly accepted risk factors associated with shoulder dystocia include fetal macrosomia, a fetus that is large for gestational age, maternal diabetes, and a prior history of shoulder dystocia [1]. Looking at first-time occurrence for multiparous or nulliparous women, the risk factors include maternal obesity, excessive gestational weight gain, maternal diabetes, and postdatism. Gurewitsch and Allen [1] state that a retrospective analysis of cases of shoulder dystocia indicates that half displayed one or more of these factors that conceivably might have been managed during the antenatal period. However, interpreted another way, the data suggest that a large proportion of mothers delivered vaginally without complications of shoulder dystocia despite risk factors [1].

Several studies, such as Overland et al [11] and Acker et al [12] noted a marked non-linear increase in the incidence of shoulder dystocia complications as a function of birth weight. Depending on the study, risks increased from 10 to 20 times from median birthrates (approximately 3500 to 3999 g) to infants with birth weights greater than 4500 g. Figure 5 from Overland et al [11] illustrates proportions of shoulder dystocia associated with nearly two million births in Norway as a function of birth weight for parous and primiparous women. The strong association of shoulder dystocia delivery with higher birth weight is particularly evident. The study reported that approximately 75% of all cases occurred with birth weight greater than 4000 g. Over the range of common birth weight in this study (3000-3499 g to >5000 g), the proportion of deliveries with shoulder dystocia increased about a 100-fold (Figure 5). Also, the risk for parous women, women who have already given birth once or more, with high birth weight infants is greater than that for nulliparous women who become first-time mothers, primiparous, with similarly high birth weight infants according to the text of the paper itself.

Studies show consistently that the risk of complications from shoulder dystocia increases along with infant birth weight. Yet, these findings do not form a basis for prediction because some 40% to 60% of shoulder dystocias are associated with birth weights less 4000 g, and 70% to 90% of macrosomic infants are delivered without this complication [2].

Maternal hyperglycemia (elevated glucose levels) has also been identified as a risk factor for shoulder dystocia [1]. This condition contributes to infants with higher birth weights, which many studies conclude is the causal link with shoulder dystocia [2]. The risk appears most developed with subclinical symptoms of gestational diabetes because these women often receive less attention in managing issues of weight gain, diet, and fetal growth patterns [1]. Risk factors related to gestational weight and to hyperglycemia can be reduced through monitoring of fetal growth through ultrasound and by glucose screening mothers.

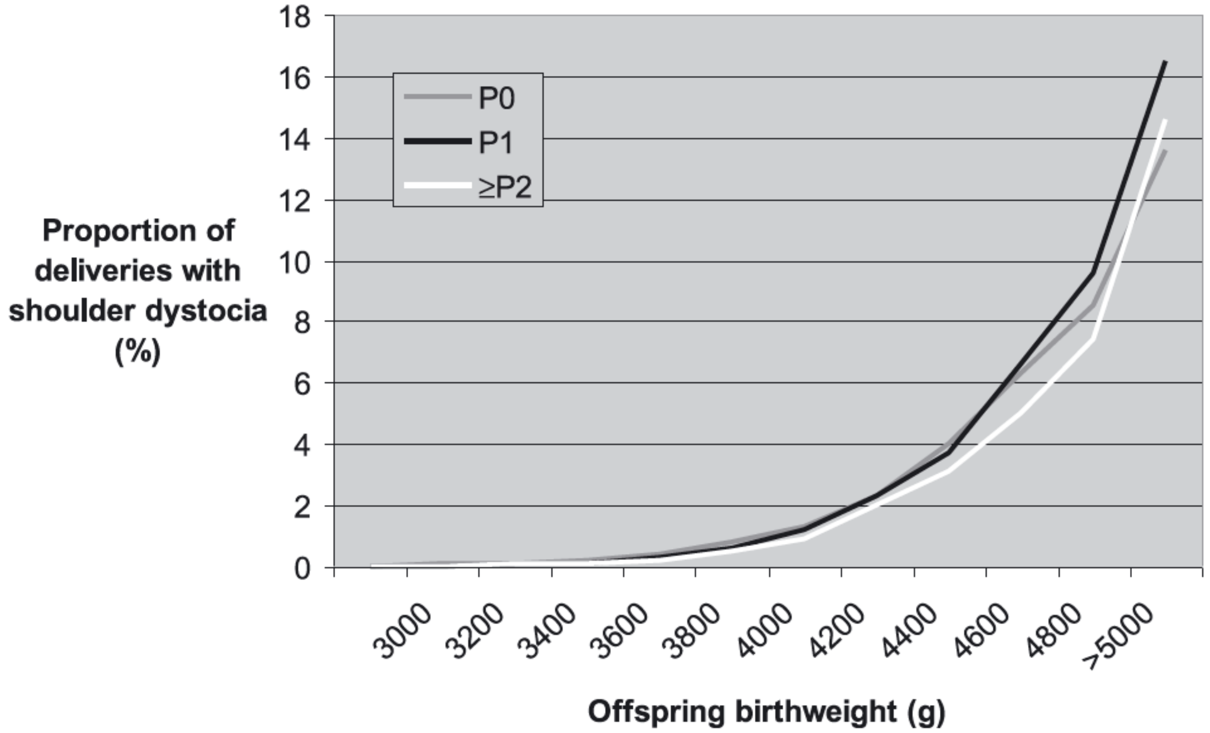

Figure 5: Proportion of deliveries with shoulder dystocia as a function of birth weight and parity (P0, P1, >P2) (from [11])

Another indicator of the risk for shoulder dystocia is its occurrence in a previous birth. Gurewitsch and Allen [1] reviewed data from a number of previous studies and found a recurrence rate of 6% to 20%. This rate is about 10 times greater than that noted for the general population [13]. In an earlier review, Gherman et al. [2] considered such findings to be equivocal because of inherent limitations in many different aspects of the studies.

Maternal Maneuvers

Once a severe problem of shoulder dystocia presents itself, the recommended next steps are often maternal maneuvers, such as a generous episiotomy. Traditionally, the HELPERR mnemonic has been used: call for **h**elp, evaluate for **e**pisiotomy, **l**egs (the McRoberts maneuver), suprapubic **p**ressure, **e**nter maneuvers (internal rotation), **r**emove the posterior arm, and **r**oll the mother [14]. Interestingly, Ansell points out that there is no compelling data on this particular order for instituting the various maneuvers, especially because the last maneuver tends to be especially effective compared to the other maneuvers. She also cites data from practitioners that some of the maneuvers involved with the mnemonic are difficult to remember and hard to apply [15]. In addition, other maneuvers than those in the HELPERR mnemonic may be used.

Episiotomy is a surgical cut on the perineum or vaginal wall that is commonly thought to relieve shoulder dystocia. However, Gurewitsch et al. [16] indicate that "this claim lacks evidence-based foundation", citing other studies. Clearly, episiotomy affects soft tissue rather than the bony obstruction giving rise to shoulder dystocia, so it does not offer a logical solution for resolving the problem. A recent study [17] also suggests that there are no neonatal benefits from an episiotomy and that there is no difference in brachial plexus injury rates between shoulder dystocia deliveries managed with an episiotomy and those managed without that technique. There are also many maternal disadvantages to episiotomy, some severe and long-lasting. For example, maternal anal sphincter trauma and severe perineal trauma were significantly more common after episiotomy, which is counterproductive, given that episiotomies are often performed with the goal of preventing perineal trauma [16]. During postpartum recovery, episiotomies may increase perineal pain, lead to trouble defecating [18], cause sexual intercourse to become painful, and result in insufficient lubrication during sexual intercourse [19]. As such, some studies question if an episiotomy is really necessary with shoulder dystocia [17].

The McRoberts maneuver consists of flexing the maternal thighs up onto the maternal abdomen, flexing and abducting the maternal hips. Thus, the sacral promontory is flattened, causing cephalad rotation of the pubic symphysis [14], which can change the maternal geometry to effectively increase the pelvic outlet by 1 cm, with reported success rates of 42% [15]. However, a randomized trial of the McRoberts position versus the lithotomy position, where the mother is positioned with her feet above or at the same level as the hips (often in stirrups), was made by a single physician using custom glove with force sensors to record the amount of force that was exerted on the fetal head. This study found no reduction in clinician force applied to the infant associated with the McRoberts position as compared to the lithotomy position, raising questions as to the usefulness of the McRoberts position [20]. However, Buhimschi et al. found that the McRoberts position increases intrauterine pressures by almost double, which may partially explain why that position facilitates delivery [21].

Suprapubic pressure, also known as Rubin's I maneuver, is pressure applied to the mother's abdomen behind the fetal anterior shoulder, aiming to push the fetal shoulder under the symphysis pubis to reduce the bisacromial diameter. It has success rates of 54.2-58% when performed with the McRoberts maneuver [15].

Rolling the mother onto all fours, also known as the Gaskin maneuver, increases the true obstetric conjugate by up to 1 cm and the pelvic outlet by up to 2 cm, according to radiographic studies. It successfully relieves shoulder dystocia with a rate of 83%. Despite the excellent success rate, the Gaskin maneuver is mentioned last in HELPERR, possibly because rolling the mother onto all fours makes it more difficult for the birth assistant to observe the birth [15]. Also, if intravenous lines and fetal monitoring equipment are present, it may make rolling the mother over on all fours problematic. When the Gaskin maneuver fails, the "running start" position may be transitioned to, where the mother, on all fours, raises one leg and places the sole of the foot down flat, which may dislodge the trapped shoulder from the symphysis pubis [22].

Cephalic replacement, also known as the Zavanelli maneuver, is a desperate emergency solution for intractable shoulder dystocia. The fetal head is replaced into the vagina and the infant is then extracted via cesarean section. Cephalic replacement has a 92% success rate, but a significant minority of mothers and infants suffered considerable morbidity, including neonatal seizure and permanent brachial plexus palsy, and 10% of mothers required blood transfusion. Out of a study of 59 cases, two of the mothers required hysterectomy due to ruptured uterus [23].

Abdominal rescue, also known as hysterotomy, is a rare technique used in cases of bilateral shoulder dystocia only after even cephalic replacement has failed. A cesarean section is performed, allowing the anterior shoulder to protrude through the incision. Then the anterior shoulder can be pushed off the oblique to allow the posterior shoulder to be delivered vaginally [23].

In developing countries, symphysiotomy is sometimes used to treat shoulder dystocia. Symphysiotomy is the surgical cutting of the cartilage of the pubic symphysis to widen the pelvic diameter by up to 2 cm. There is significant maternal morbidity, including risks of urethral and bladder injury, infection, pain, long-term walking difficulty, incontinence, and depression. The infant morbidity associated with symphysiotomy is also significant. In three recent cases in the United States, all infants died of asphyxia [23].

The left lateral side-lying position for the mother has fewer than expected shoulder dystocias as compared to a back-lying position, possibly because it allows more room for movement of the baby toward the mother's sacrum [22].

Fetal Maneuvers

Beyond simple downward traction on the shoulders, fetal manipulations include a variety of techniques designed to “optimize the geometric relationship between the fetal shoulder width and the maternal pelvic dimensions” [16]. Sometimes these manipulations are perhaps erroneously thought to be facilitated by episiotomy, but it appears that manipulations themselves are critical to reducing the risk of brachial plexus injury. Fetal shoulder dystocia maneuvers are generally considered effective in reducing injuries by lowering the traction forces applied to the head in comparison to maneuvers like McRoberts positioning that uses assistants to reposition the mother [1].

The Rubin's maneuver, which is sometimes confused with the Wood's screw maneuver, consists of pressure on the posterior aspect of the anterior shoulder. This pressure causes adduction of the anterior shoulder toward the fetal chest, which assists movement of the fetal bisacromial diameter into the larger oblique diameter of the maternal pelvis [22].The adducted diameter is smaller than the abducted diameter, which facilitates delivery [23].

The Wood's screw maneuver is usually done after the Rubin's maneuver. The anterior surface of the posterior shoulder is abducted upwards to cause 180^{o} rotation. This rotation should release the impacted anterior shoulder. This movement may "corkscrew" the fetal shoulders through the maternal pelvis. It can be repeated a second time if it fails the first time. The Wood's screw and Rubin's maneuvers are thought to have a low risk of causing brachial plexus injury, because they do not use traction on the fetal head [22]. However, the Wood's screw maneuver does have some risk for the birth assistant, as there is a reported case of an obstetrician suffering a spiral fracture in the right fourth metacarpal bone due to performing Wood's maneuver [24]. Parallel forceps may be used during this maneuver [23].

Delivery of the posterior arm requires the birth assistant to insert his or her entire hand into the vaginal canal to sweep the fetal arm forward across the fetal chest to deliver the posterior arm, which effectively decreases the fetal bisacromial diameter, facilitating delivery [22]. This maneuver is associated with fetal injury of the humerus (as high as 12% of the time [15]) and/or clavicle, though those injuries heal well [23] and a 12-fold increased risk of 4th degree perineal laceration [15].

Axillary traction may be used in cases where there is little room for the birth assistant's hand to maneuver [15]. The birth assistant hooks a finger into the fetus's posterior axilla, which is the armpit region, and pulls outward to extract the posterior arm. This maneuver also prevents traction on the brachial plexus [22]. Axillary traction takes about 20 seconds to deliver the baby if effective, which has led some to suggest it should be used more often [15].

Cleidotomy, the deliberate fracture of the clavicle, is sometimes suggested in theory but is discouraged in practice. While spontaneous clavicle fractures occur relatively frequently, deliberate fracture or cutting of the clavicle is difficult to perform. There are no reported cases of cleidotomy on a live fetus, though it is sometimes used to remove a dead fetus [23].

Pressures and Forces during Shoulder Dystocia Deliveries

Brachial plexus injuries related to shoulder dystocia are usually considered to be most strongly correlated with traction applied by the clinician [1]. In the literature, traction is measured as a force with units of pounds or Newtons. The rarity of shoulder dystocia and the difficulty in making measurements with human patients commonly has meant that forces need to be inferred. A variety of investigative approaches have been used, such as (i) physical models using fetal and maternal replicas, (ii) estimates of traction forces based on pressure measurements from gloves, and (iii) mathematical models of forces developed for routine and shoulder dystocia deliveries and maternal maneuvering [2].

One of the earliest series of physical modeling studies [25] used maternal pelvic and fetal models, a tactile sensing glove, and a microcomputer data acquisition system to measure fetal shoulder extraction forces. This study found that an increasing peak force was required to extract the anterior shoulder with increasing clavicular diameters. Research with the same apparatus by Allen et al. [26] found that peak forces applied by the clinician were 47 Newtons for routine deliveries and 100 Newtons with shoulder dystocia. Subsequent studies with a birth simulator, which involved 11 female and 28 male clinicians, provided estimates of peak horizontal forces with shoulder dystocia to be 125.3 Newtons and 108 Newtons, respectively, for the two groups, men and women. A review of pertinent literature [1] suggests that brachial plexus injuries begin once clinician-applied forces exceed approximately 27.5 lbs. (122 N), which is close to the elastic limit of 30 lbs (133 N) for nerve stretch according to cadaveric studies [1].

Another important contribution to knowledge has come from the application of theoretical approaches to mathematically model the pressures associated with shoulder dystocia. Gonik

[27] used a force balance approach to estimate the compressive stress or pressure at the contact area between the neck of the fetus and the symphysis pubis. Although the study was limited by many assumptions and simplifications, it highlighted differences in the exogenous force (clinician applied) and endogenous force (expulsive forces, such as maternal bearing down, and uterine contractions). Calculations suggested that delivery pressures, applied to the contact area at the symphysis pubis and attributed to the mother (91.1 to 202 kPa) were four to nine times higher than traction pressures exerted by the clinician (22.9 kPa).

This result is important because it points to the possibility for endogenous forces to contribute to injuries from shoulder dystocia. For example, it helps to explain cases of brachial plexus injuries when routine traction forces were used or with infants with normal birth weights. The modeling helps validate observations from another study [28] that Erb's palsy in one third of cases was associated with unusually strong expulsive efforts and rapid deliveries.

Gonik continued efforts in modeling with a more sophisticated mathematical-dynamical model [29], [30]. These studies continued to confirm the significant role of expulsive forces and showed an advantage of McRoberts positioning of the pelvis in reducing the contact force behind the symphysis pubis and the overall delivery force (exogenous plus endogenous). Modeling also suggests that optimal positioning of the fetal head (axial position) during traction produced less stretching of the brachial plexus [30].

Since the early 2000s, work at Johns Hopkins University has continued on the development of an instrumented birthing simulator. The goal of that work was to improve knowledge in the birthing processes and improve training for cases complicated births [31]. Features of the maternal simulator included anatomically correct bony elements, deformable skin, and a pneumatic uterine expulsive system. Pelvic rotation can be precisely controlled and monitored as well as the pressure applied to the fetal model [31]. The fetal model includes model vertebrae, conductive rubber sensors to monitor neck extension, and a rotary potentiometer to measure neck rotation. The fetal model also provides the capability for monitoring of the brachial plexus nerves, which are incorporated as conductive rubber strips fixed to the vertebrae. Pressures applied by a clinician were measured using piezoresistive sensors on gloves and a wireless electromyography (EMG) device. This device monitors muscle contractions in the forearm, which can be calibrated in terms of hand-applied forces [32]. A data acquisition system displayed and collected the data.

Studies using the simulator have helped elucidate origin of injuries to nerves of the brachial plexus during the second stage of labor (descent, crowning and restitution) [33]. A particularly surprising result was that stretching of the brachial plexus and both neck rotation and stretching occurred in all types of second-stage labors (routine and shoulder dystocia). It helped to explain cases of injuries in lighter-weight infants in apparently routine births [12]. For example, Allen and Gurewitsch [34] described a case of temporary Erb-Duchenne palsy in a normal delivery without traction or shoulder dystocia.

The birthing simulator also has been used to compare three common shoulder dystocia maneuvers McRoberts (hyperflexing mother's legs to abdomen), anterior Rubin's and posterior Rubin's (rotation of fetal shoulders) [35]. Results of these experiments suggested that the Rubin's maneuvers required significantly less traction forces than McRoberts with less stretching of the brachial plexus. The anterior Rubin's (30^o counterclockwise rotation of the anterior shoulder) maneuver was found to be marginally better because of more favorable positioning of the head, which permits forward flexing [35].

Chapter Three: Study

Abstract

Shoulder dystocia is a serious obstetric emergency. Brachial plexus injuries can be caused by hyperextension of the neck or misalignment of the fetal head during traction. To address knowledge gaps relating to clinician applied forces associated with deliveries, this study analyzed hand pressures applied by obstetricians in mock deliveries and suggests improvements for pressure-sensing gloves. The subjects were obstetricians, both residents and staff, recruited from the University of Kansas Hospital. A Laerdal PROMPT Birthing Simulator was used for the mock deliveries. The experimental design involved two pressure measurement strategies. Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) with twelve pressure sensors for each hand provided pressure measurements with time. Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] recorded areas where pressure was applied.

The two measurement techniques compared well in capturing the spatial distribution of pressures across the hands. Both indicated pressure was exerted primarily with the middle, index, and ring fingers. Pressures due to the thumb and the palm were significantly smaller. Nonzero average pressures produced by the left hand were higher than the right but not significantly so. The pressure-film data indicated that pressures applied by resident and staff subgroups were comparable, except for the left hand where staff members applied significantly higher pressure with the little finger.

With the glove sensors, there were three conditions: downward traction only, excessive force, which simulated conditions where damage could occur, and full delivery. The downward traction only, excessive force, and full delivery conditions had similar results with few

significant differences. The residents and staff had few significant differences for these conditions between each other and between the conditions. The staff may have been more adept at using all the regions of their hands efficiently to apply balanced pressures.

The glove sensors covered a range from 0 to 20 psi (0 to 0.14 MPa). If pressures exceeded the maximum of the range, the accuracy of the data decreased. This suggested that perhaps the sensor range should be improved in newer designs. Other important design changes could include increasing the numbers of sensors.

Introduction

Shoulder dystocia occurs during a delivery when the infant's anterior shoulder, relative to the mother, lodges against the pubic symphysis following the delivery of the head [1]. Typically, shoulder dystocia is a potentially life-threatening obstetric emergency because of the potential for anoxic injuries and requires fast action on the part of the clinician. Strategies for dealing with shoulder dystocia include, but are not limited to, simply applying larger forces than usual to the fetal head to free the shoulder that is stuck or delivery maneuvers that are applied to the mother, the infant, or both. However, applying large forces to the fetal head is problematic because it can cause injuries of varying severity, such as humeral fracture, clavicle fracture, or brachial plexus injury [1].

Clavicle and humeral fractures are considered to be less severe injuries and always heal during the neonatal period [1]. Much more serious is brachial plexus injury, which involves injuries to the nerves of the brachial plexus. They originate from the segments C5, C6, C7, C8, and T1 of the spinal cord and control muscles in the arm, wrist, and hand. Injuries to the brachial plexus are thought to be related to forceful stretching caused by hyperextension of the neck. Less serious are upper trunk injuries that resolve themselves relatively quickly. More serious stretching, rupturing, or avulsion can result in (i) Erb's palsy, which is associated with damage to the upper roots and impairs muscle function in the shoulder and elbow, (ii) Klumpke's palsy, which involves injuries to nerves of the middle and lower trunk, and affects the elbow, forearm, and hand. These injuries may end up being permanent even after neurosurgery [2]. Other injuries could involve all of the roots.

Studies have examined the association of brachial plexus injuries and traction forces applied by clinicians. However, the rarity of shoulder dystocia and difficulties in making measurements with human patients commonly has meant that forces have necessarily been inferred from a variety of investigative approaches.

Research with a physical model found that peak forces were 47 N for routine deliveries but ranged from approximately 100 to 125 N for cases of shoulder dystocia [25]; [26]. Literature [1] suggests that brachial plexus injuries begin once clinician-applied forces exceed approximately 27.5 lbs. (122 N), which is close to the elastic limit of 30 lbs. (133 N) for nerve stretch [1]. These estimates are in line with studies on cadavers, which showed that serious nerve damage occurred with laterally applied (relative to fetal spine) traction of 44 pounds [9].

Mathematical modeling has been useful in establishing the role of expulsive forces and uterine contractions as a component of delivery forces available to cause injuries of the brachial plexus [27]; [29]. Calculations suggested that delivery forces, applied to the contact area of the shoulder at the symphysis pubis and attributed to the mother (91.1 to 202 kPa), were four to nine times higher than traction forces exerted by the clinician (22.9 kPa) [27].

Modeling has also pointed to advantages in McRoberts positioning of the pelvis in reducing the overall delivery force. As well, optimal positioning of the fetal head (axial position) during traction produced less stretching of the brachial plexus [30].

Empirical observations have long suggested maternal or fetal maneuvers have the potential to reduce delivery forces required to address a shoulder dystocia problem. Yet, with the exception of the model study noted above, there is a major gap in knowledge concerning the relative advantages of various maternal and fetal maneuvers in reducing forces. Traditionally, the HELPERR mnemonic has been used: call for **h**elp, evaluate for **e**pisiotomy, **l**egs (the McRoberts maneuver), suprapubic **p**ressure, **e**nter maneuvers (internal rotation), **r**emove the posterior arm, and **r**oll the mother [14]. Interestingly, Ansell [15] points out that there is no compelling data on this particular order for instituting the various maneuvers, especially because the last maneuver tends to be especially effective compared to the other maneuvers.

The reviews here thus indicate that there are important gaps in specific quantitative knowledge related to traction forces and their orientations during deliveries. Moreover, the reductions in forces through delivery maneuvers are also not well known. The present study is an initial first step in a larger project designed to contribute to knowledge of the pressure and force thresholds capable of creating brachial plexus injuries. Specific objectives of the project are to determine the maximum traction forces that might be applied and to validate the pressure-sensing gloves and establish their efficacy in research and teaching.

This current study is focused on gathering preliminary data, on validating that the pressure sensors of the gloves are correctly placed, and on generating recommendations to create an improved version of the gloves for future segments of the project. If the pressure sensors of the gloves are not correctly placed, this study seeks to determine where the pressure sensors should be placed for proper data collection coverage. This study will also determine if the data gathered often rises over the maximum pressure threshold of the sensors so as to be able to make a recommendation for the maximum pressure threshold of the sensors for the next generation of gloves.

Methods

The basic strategy involved with the study was to measure time varying pressures exerted on an infant mannequin by obstetric clinicians through a simulated delivery. The study subjects were physicians, both residents and staff, recruited from the University of Kansas Hospital Obstetrics and Gynecology Department. They participated in this study after providing informed written consent as approved by the University of Kansas Human Subjects Committee (Appendix A.1). Their level of training ranged from residents (6) to staff physicians (4), and the subjects were a mix of males (3) and females (7). They identified themselves as either right handed (8) or left-handed (2). No subject identified as ambidextrous. Subjects wore hospital scrubs or civilian clothing. Each subject was assigned a participation number.

A Laerdal 376-00550 PROMPT Birthing Simulator – Force Monitoring was used for the experiments, which, as of 2008, was the only simulator of its kind in the United States [36]. The simulator consists of a maternal mannequin that includes the upper legs, pelvis, and lower abdomen (Figure 6). The bony pelvic structure is represented correctly in the mannequin, and the thighs are articulated (Figure 7). The infant mannequin, also fully articulated, weighs 2300 g and includes a placenta with umbilical cord (Figure 8). The inherent force monitoring system in the PROMPT Birthing Simulator was not used due to being inoperative at the time of this study. The simulated placenta was also not used, as it was not relevant to the aims of the study.

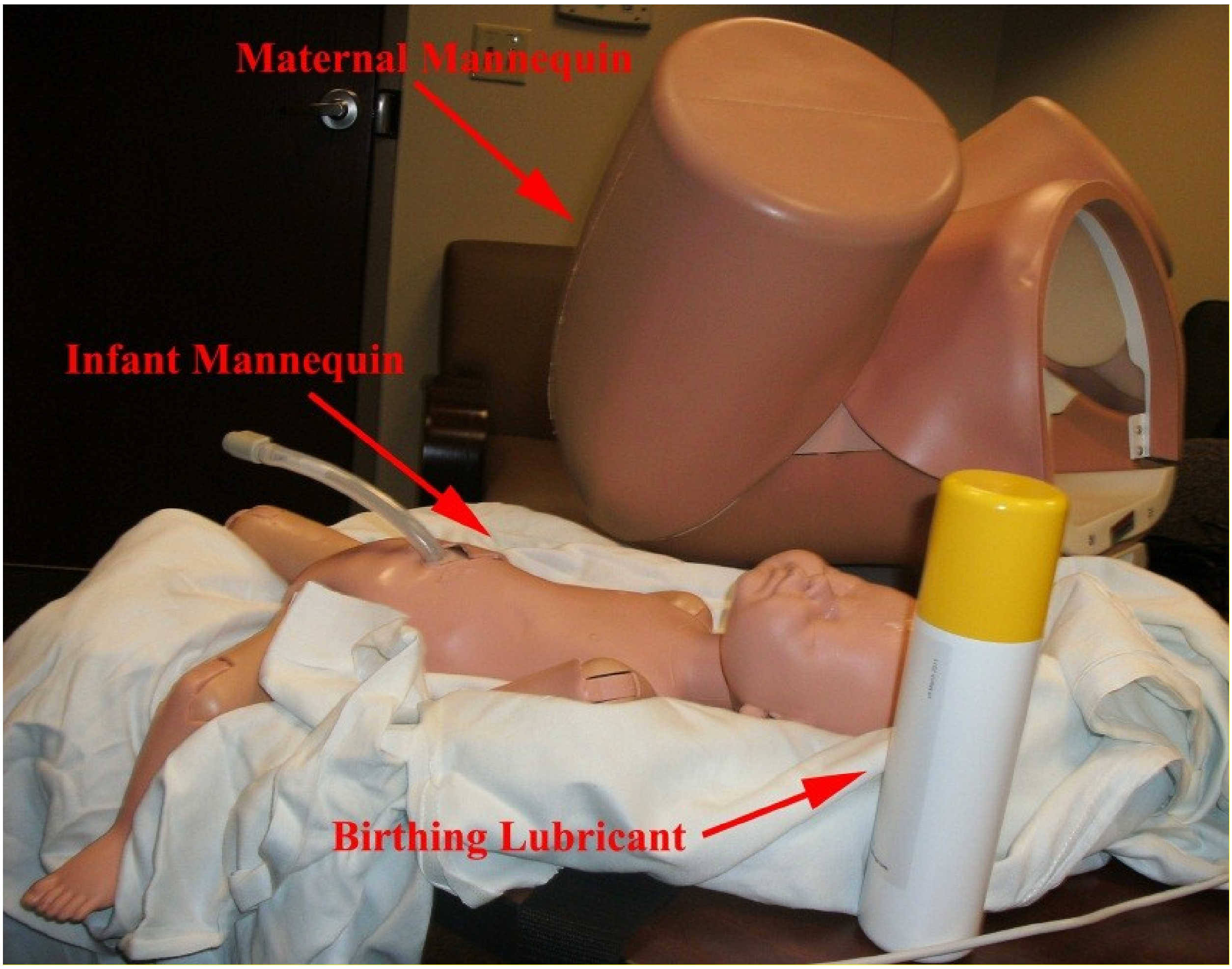

Figure 6: The PROMPT Birthing Simulator showing the maternal and infant manequins.

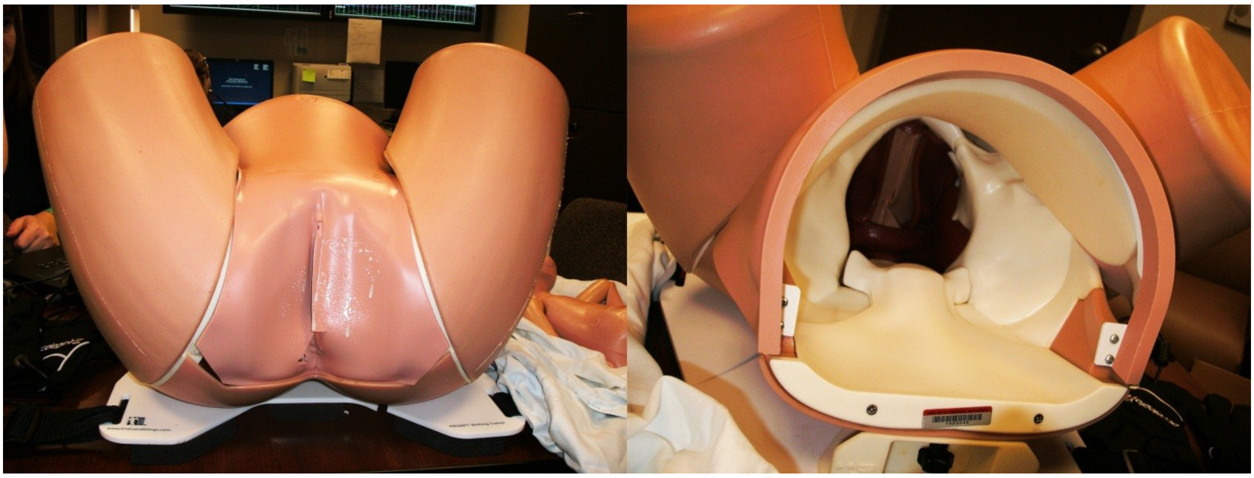

Figure 7: The maternal mannequin shown from the front and back.

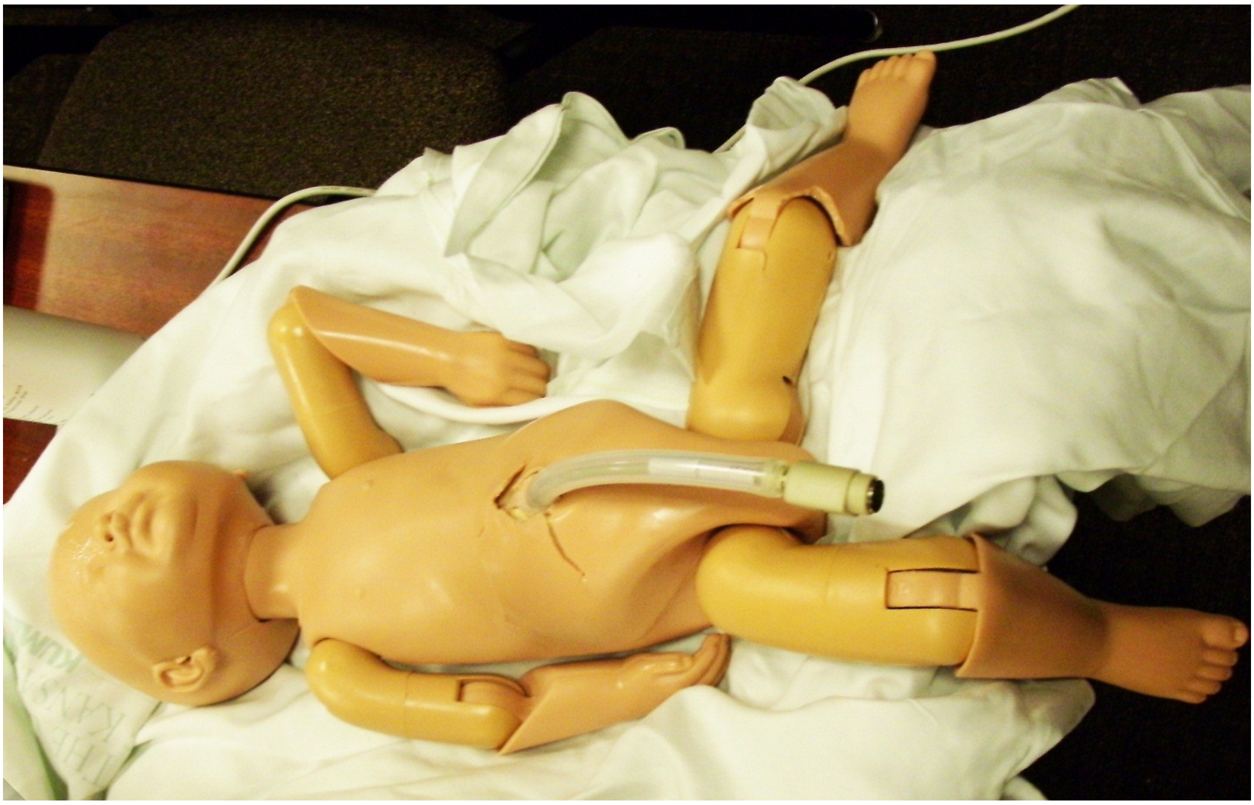

Figure 8: The infant mannequin shown in a close-up view.

The birthing system can simulate different delivery positions including; semi-recumbent, lithotomy, McRoberts, Gaskin (all fours position) and various delivery complications including shoulder dystocia. To ready the maternal simulator for operation, the maternal mannequin was securely strapped to a table to prevent it from shifting its position during the experiment. The assistant sprayed birthing lubricant upon the infant mannequin to help prevent tearing of the mannequins and ease the simulated delivery. Next, the infant mannequin was placed into the pelvic cavity of the maternal mannequin.

The maternal mannequin was set up in the McRoberts position. A video camera recorded the trials. Each subject was instructed to describe orally various features of the simulated delivery, recorded by the video camera as he/she performed the different maneuvers. The assistant prevented the infant mannequin from being delivered until the physician had performed appropriate maneuvers and provided obstructive resistance against the physician's traction until appropriate downward traction had been performed. The assistant's resistance was inherently variable.

The particular emphasis in this study was to quantify forces exerted by traction during the simulated delivery. The experimental design involved two measurement strategies, gloves with discrete pressure sensors attached and pressure sensitive film. The discrete pressure sensors provide pressure measurements as a function of time at a small number of discrete points through the simulated delivery. The pressure sensitive film recorded maximum pressures for the fingers and palms.

Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) were used with FSA 4.0224 software to measure and capture pressure in pounds per square inch (psi) at a sampling rate of 50 Hertz. Each glove had twelve pressure sensors on the palmar side of the hand, two on each digit, roughly distal and proximal, and another two sensors on the fifth metacarpal (the palm proximal to the digitus minimus). Each sensor was identified as belonging to either the left or right hand with a unique index number (Figure 9).

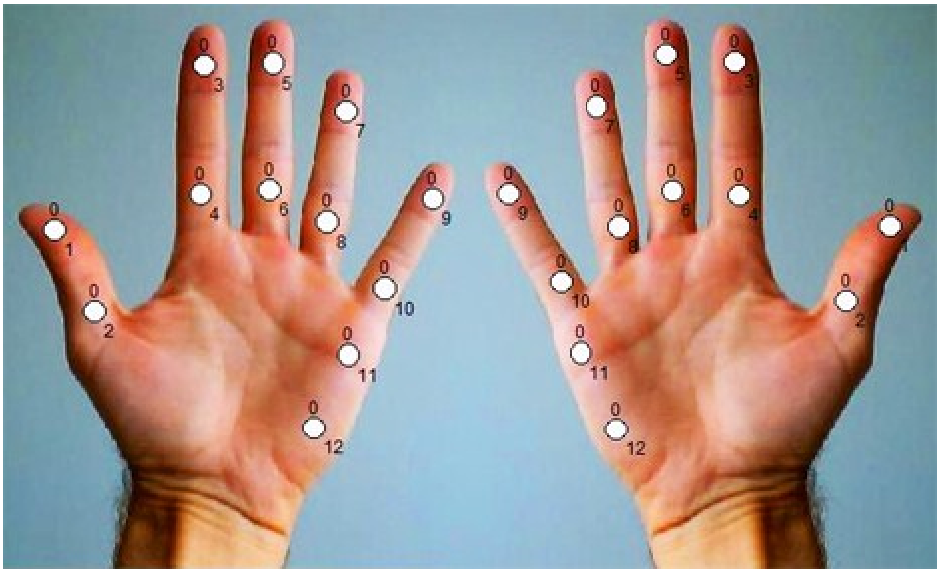

Figure 9: Index for the sensor positions on the left and right hands. Each sensor samples pressures (here the pressures are zeroed out) at 50 Hz.

Figure 10: Photograph of the FSA glove system showing the sensors fastened on each hand. The sensors are square in shape (8mm x 8mm) and covered by Teflon.

The sensors have a dynamic range of from 0 to 20 psi (0 to 0.14 MPa). Sensors are mounted individually at the end of long leads, which are connected to the data acquisition system. The gloves are comfortable and flexible (Figure 11). They provided the subjects with appropriate flexibility required to undertake the simulated delivery.

Figure 11: The photograph shows the glove as worn by the subjects.

In addition to the pressure sensitive gloves, Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] was also used. This film has a variety of uses in measuring pressure and pressure distributions between two surfaces; in this case between the subject's hands and the infant mannequin. The type of film for this study records pressure in a range from 0.05 to 2 MPa (7.25 to 29.0 psi). In practice, the pressure film records areas where pressure is applied as a red color. The color density (e.g., light pink to red) varies according to the magnitude of the pressure. Image processing with Fujifilm calibration curves (sample color density versus pressure) provides a way to create quantitative pressure maps (± 10%). The calibration curves vary as a function of relative humidity.

In all conditions, the subjects wore the pressure sensitive gloves. In one trial of the first condition, the subjects also wore pressure sensitive film. Film was pre-cut into a hand shape of consistent but arbitrary shape and size and placed upon the subject's gloved hands. The two sheets, the color-forming A-film and the color-developing C-film, were aligned with each other such that when the subjects touched objects and exerted pressure, the C-film would develop and provide a color density map for the hand (Figure 12).

Figure 12: Illustrative example of the color density map that appeared once the film developed. In this example, the largest pressures are recorded near the tips of the fingers (darkest red).

During a simulated delivery over a number of minutes, the film records the maximum pressure observed at specific points sometime during the experiment. Thus, results should not be interpreted as a snapshot in time of pressures.

Before a measurement was made, a sheet of protective plastic was placed over the sheets of film to prevent stray oils from causing discoloration. The protective plastic sheet was secured to the gloves with 1/2" 3M Scotch© Magic™ tape. Following data collection for the film trial, the sheets of pressure film were placed into protective sleeves and labeled with the subject's number and which sheet corresponded to which hand, left or right. A thermometer and barometer were used to record the temperature and relative humidity at the time when the pressure film was used.

After the film had at least 30 minutes to develop, as per the manufacturer's guidelines, the developed film was scanned against a black background on a Canon Pixma MG 5220 scanner as 600 DPI TIFFs. Then, the TIFFs were image processed in Adobe Photoshop CS5 (64 bit) into 8 color GIFs containing these specific named web colors: White (#FFFFFF), Pink Lace (#FFCCFF) Lavender Rose (#FF99FF), Pink Flamingo (#FF66FF), Razzle Dazzle Rose (#FF33FF), Fuchsia (#FF00FF), Hollywood Cerise (#CC0099), and Black (#000000) which correspond to the scaling colors on the factory-supplied "Momentary pressure standard chart". Next, the temperature and relative humidity were used to determine how the color values scaled to pressures on the "Momentary pressure standard chart", which was used because the pressures applied during the testing were transient, not sustained. A MATLAB script (Appendix A.2) was used to determine the numbers of pixels that were associated with each color, to eliminate the black pixels as background, and to develop a weighted pressure average of each film scan and each segmented region of the hand: the palm, the thumb (digitus primus), the index finger (digitus secundus), the middle finger (digitus medius), the ring finger (digitus annularis), and the little finger (digitus minimus). The common terms for the areas of the hand will be used in this study to facilitate understanding for the engineering audience. A template, shown in Figure 13, was used to process the regions into consistent sizes and shapes by always segmenting along the same lines each time.

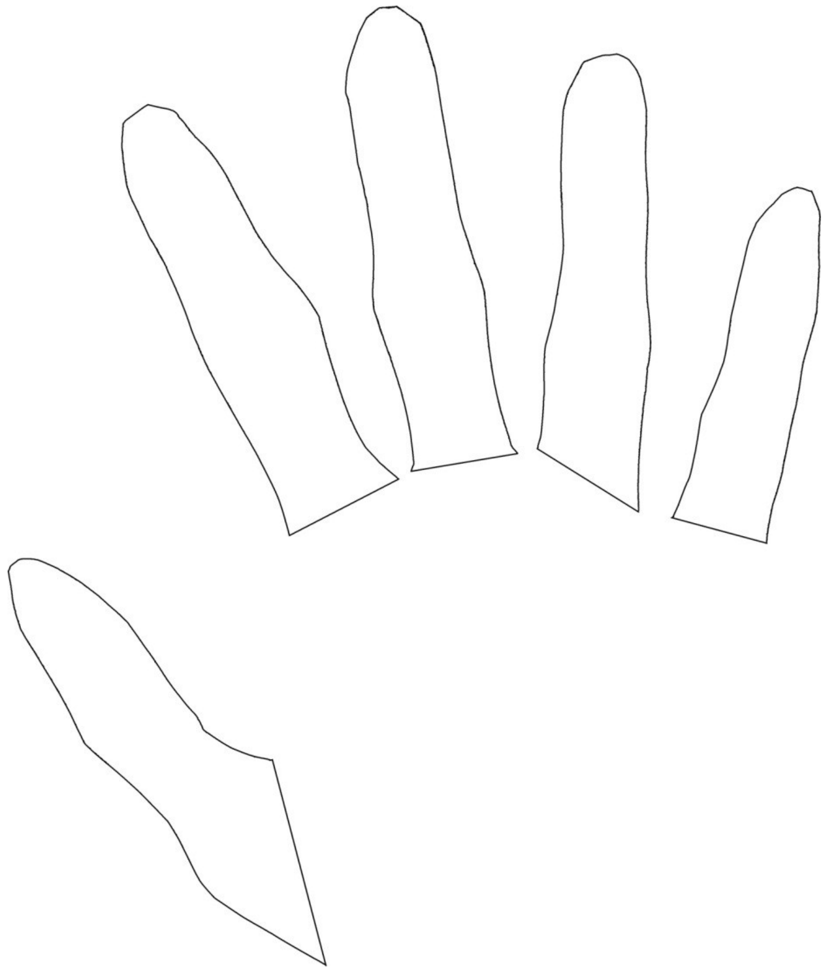

Figure 13: The template used to segment the pressure film scans into specific regions.

Design of the Simulated Delivery Conditions

Each subject was asked to participate in three major conditions that are monitored for pressures. Some conditions involved several trials or variations. For the first two trials of Condition 1, each subject wore pressure sensitive gloves. He/she was asked to perform solely downward traction on the shoulder and head of the infant mannequin during a simulated shoulder dystocia delivery and to not complete delivery of the infant mannequin. These two conditions established the magnitude of pressures generated during downward traction and where these pressures were distributed on the hands. The third trial of the Condition 1 involved both the pressure sensitive gloves and the pressure measurement film.

For Condition 2, of which there was only one trial, the subject was asked to perform a simulated shoulder dystocia delivery that would model improper, dangerous practice with excessive force that might cause brachial plexus injury. The subject wore pressure gloves, explained what he or she was performing, and was also videotaped for this trial.

For Condition 3, which included three trials, the subject again wore the pressure gloves and was videotaped. He/she was instructed to proceed with a full delivery of the infant mannequin, which included downward traction to free the trapped shoulder and ended in the subject holding the delivered infant mannequin.

Data from the sensors of the gloves was loaded into MATLAB and processed using the scripts listed in the Appendix (A.3). These scripts determined the nonzero mean for each sensor position. The nonzero mean was selected as opposed to the zero-inclusive mean because each subject used a different startup time where the gloves were not in contact with the infant mannequin. Leaving in the zero values would artificially lower the mean in an inconsistent fashion. Use of the nonzero mean ensured that data points only are considered when pressure is actually being exerted. This strategy is thus more appropriate, given the aims of the study. The nonzero means were analyzed in Excel to determine which sensors and regions of which hand had the highest and lowest pressures, whether the residents or staff used higher pressures, to determine significance via unpaired two-tailed t-tests ($p<0.05$), and, as a last step, to convert the native psi measurement of the glove software to MPa. This analysis bore out the study goal of determining if the sensors are correctly placed and gathering preliminary pressure data. Handedness, gender, and size of hands were not considered in this study due to the small sample size meaning that there was low likelihood of being able to determine if those factors were significant. The left/right orientation of the infant mannequin will also not be considered due to difficulty of determination. Appendix A.4 contains sample graphs of the pressure versus time plots, but this study does not examine the pressures at specific times, instead examining the average pressures over time.

To determine how often the glove sensors peaked out at the maximum value of 20 psi, MATLAB code scripts, available in the Appendix (A.5), were used. Then, Excel was used to hypothetically examine the effects of higher pressures on the accuracy of the data.

Results

Part 1 - Film Pressure Measurements

The Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] results are summarized in Table 1, which shows the average pressure across all subjects per region and compares left and right for all subjects. While the left hand tends to have higher pressures than the right, this tendency is not statistically significant. The only significant relationship between the left and right hands according to the pressure film is that the left and right little fingers apply significantly the same overall pressure. The middle, ring, and index fingers apply the highest pressures. The palm, thumb, and whole hand exert the lowest pressures.

Region	**Average Region Pressure (MPa)**	**STDEV.S**	**Left Average Region Pressure (MPa)**	**STDEV.S**	**Right Average Region Pressure (MPa)**	**STDEV.S**	**Left Versus Right T-Test**
Whole Hand	0.005	0.003	0.005	0.004	0.004	0.002	0.38
Palm	0.002	0.003	0.003	0.004	0.001	0.001	0.29
Thumb	0.004	0.004	0.005	0.005	0.003	0.003	0.32
Index	0.010	0.012	0.012	0.015	0.008	0.008	0.44
Middle	0.017	0.014	0.020	0.019	0.015	0.007	0.40
Ring	0.012	0.012	0.014	0.013	0.011	0.012	0.67
Little	0.006	0.005	0.006	0.005	0.006	0.005	0.99

Table 1: Weighted average across all subjects of pressure film results comparing left and right by regions. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light yellow t-test cell indicates that the compared values are significantly the same.

In Table 2, the average pressures of the regions (see Figure 13 and Table 1) are compared to each other for the average of both hands to establish the significance of relationships between regions. The palm exerts significantly the lowest pressures of any region. The thumb exerts significantly lower pressures than the index, middle, ring, and little fingers. The whole hand has significantly lower pressures than the middle and ring fingers. The middle finger provides significantly higher pressures than every other region except for the index finger. The ring finger exerts significantly higher pressures than the whole hand, palm, thumb, and little finger. The index finger provides significantly higher pressures than the palm and thumb.

T-Tests	Whole Hand	Palm	Thumb	Index	Middle	Ring	Little
Whole Hand		3.8E-03	0.67	0.06	4.2E-04	0.01	0.23
Palm	3.8E-03		0.03	4.7E-03	2.5E-05	6.7E-04	9.3E-04
Thumb	0.67	0.03		0.05	3.1E-04	0.01	0.14
Index	0.06	4.7E-03	0.05		0.08	0.54	0.22
Middle	4.2E-04	2.5E-05	3.1E-04	0.08		0.23	2.3E-03
Ring	0.01	6.7E-04	0.01	0.54	0.23		0.05
Little	0.23	9.3E-04	0.14	0.22	2.3E-03	0.05	

Table 2: T-test significance values comparing regions for the average of both hands for the pressure film. The green shading of cells indicates a significant difference.

In Table 3, the average pressures associated with the regions on the left hand are examined to establish the significance of pressure relationships for the left hand. The palm exerts significantly lower pressures than the middle and ring fingers. The pressures due to the thumb and whole hand are significantly lower than the middle finger. The middle finger applies significantly higher pressures than the whole hand, palm, thumb, and little finger. The ring finger has significantly higher pressures than the palm.

T-Tests	Whole Hand	Palm	Thumb	Index	Middle	Ring	Little
Whole Hand		0.11	0.90	0.19	0.03	0.08	0.66
Palm	0.11		0.19	0.06	0.01	0.02	0.07
Thumb	0.90	0.19		0.18	0.03	0.08	0.61
Index	0.19	0.06	0.18		0.30	0.82	0.27
Middle	0.03	0.01	0.03	0.30		0.38	0.04
Ring	0.08	0.02	0.08	0.82	0.38		0.14
Little	0.66	0.07	0.61	0.27	0.04	0.14	

Table 3: T-test significance values comparing regions for the average of the left hand for the pressure film. The green shading of cells indicates a significant difference.

In Table 4, the significance of average pressures attributed to the regions is determined compared to each other for the right hand. The palm exerts significantly lower pressures than the middle and ring fingers. The whole hand and thumb provide significantly lower pressures than the middle finger. The right middle finger produces pressures that are significantly higher than the whole hand, palm, thumb, and little finger. The ring finger has significantly higher pressures than the palm.

T-Tests	Whole Hand	Palm	Thumb	Index	Middle	Ring	Little
Whole Hand		1.3E-03	0.48	0.17	1.2E-04	0.08	0.18
Palm	1.3E-03		0.02	0.02	4.5E-06	0.02	3.9E-03
Thumb	0.48	0.02		0.11	6.8E-05	0.06	0.09
Index	0.17	0.02	0.11		0.05	0.48	0.63
Middle	1.2E-04	4.5E-06	6.8E-05	0.05		0.41	4.8E-03
Ring	0.08	0.02	0.06	0.48	0.41		0.26
Little	0.18	3.9E-03	0.09	0.63	4.8E-03	0.26	

Table 4: T-test significance values comparing regions for the average of the right hand for the pressure film. The green shading of cells indicates a significant difference.

Table 5 compares results for the residents and staff. The residents tend to produce higher pressures than the staff, but this tendency is not statistically significant. For the left hand and the average of both hands but not the right hand, the staff members apply significantly higher pressures on the little finger than the residents do, suggesting perhaps that the staff learn through experience the advantage of using all of their fingers instead of neglecting the little finger. For the right ring finger alone, the residents and staff apply significantly the same pressures. For the average of both hands, the residents apply the highest pressures with the middle, index, and ring fingers and the lowest pressures with the palm, thumb, and little finger. For the average of both hands, the staff members tend to apply the highest pressures with the middle, ring, and little fingers and the lowest pressures with the palm, the thumb, and the whole hand. The palm with its relatively large area and lower exerted pressures likely accounts for the tendency of the whole hand to also have a low average.

Region		Average Region Pressure (MPa)	STDEV.S	T-Test	Left Average Region Pressure (MPa)	STDEV.S	T-Test	Right Average Region Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Residents (6)**	0.005	0.004	0.34	0.007	0.005	0.34	0.004	0.003	0.89
	Staff (4)	0.004	0.001		0.004	0.001		0.004	0.002	
Palm	**Residents (6)**	0.003	0.003	0.16	0.004	0.004	0.29	0.002	0.001	0.22
	Staff (4)	0.001	0.001		0.001	0.001		0.001	0.001	
Thumb	**Residents (6)**	0.004	0.005	0.92	0.005	0.007	0.90	0.003	0.002	0.62
	Staff (4)	0.004	0.003		0.005	0.003		0.004	0.003	
Index	**Residents (6)**	0.014	0.014	0.10	0.017	0.018	0.21	0.010	0.010	0.33
	Staff (4)	0.005	0.003		0.005	0.001		0.005	0.004	
Middle	**Residents (6)**	0.022	0.017	0.12	0.028	0.022	0.14	0.015	0.008	0.75
	Staff (4)	0.011	0.005		0.009	0.004		0.014	0.005	
Ring	**Residents (6)**	0.014	0.015	0.58	0.016	0.017	0.49	0.011	0.013	1.00
	Staff (4)	0.010	0.008		0.010	0.002		0.011	0.012	
Little	**Residents (6)**	0.004	0.002	0.01	0.003	0.002	0.02	0.005	0.002	0.33
	Staff (4)	0.010	0.006		0.011	0.006		0.008	0.008	

Table 5: Weighted average of pressure film comparing residents and staff. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Overall, the pressure film data suggest that, for downward traction, the palm applies negligible pressure compared to the fingers. The thumb also applies very low pressures. The middle, ring, and index fingers exert the highest pressures. The residents and staff generally do not have significant differences, but the staff members do apply more pressure with the little finger than the residents.

Part 2 - Pressure Sensors

Part 2.1 - Traction Only

The first series of results examines the pressures related to traction only. Table 6 compares the average of all subjects nonzero means for the left and right hands. The left hand tends to produce higher pressure than the right, but this trend is not usually statistically significant. Significant pressures differences are, however, measured on sensors 3, 6, 7, which are all located on the fingers. Sensor 3 is the distal sensor on the index finger. Sensor 6 is the proximal sensor on the middle finger. Sensor 7 is the distal sensor on the ring finger.

Sensor	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	Left Versus Right T-Test
Whole Hand	0.0072	0.0097	0.0078	0.0107	0.0067	0.0085	0.20
1	0.0045	0.0054	0.0061	0.0071	0.0030	0.0025	0.07
2	0.0026	0.0049	0.0013	0.0008	0.0035	0.0062	0.21
3	0.0160	0.0185	0.0228	0.0231	0.0085	0.0052	3.2E-03
4	0.0051	0.0065	0.0066	0.0083	0.0034	0.0033	0.08
5	0.0108	0.0065	0.0091	0.0071	0.0127	0.0105	0.13
6	0.0057	0.0036	0.0073	0.0037	0.0045	0.0030	0.01
7	0.0109	0.0105	0.0081	0.0052	0.0139	0.0136	0.04
8	0.0060	0.0064	0.0052	0.0049	0.0070	0.0079	0.32
9	0.0070	0.0070	0.0064	0.0059	0.0077	0.0080	0.49
10	0.0069	0.0083	0.0070	0.0056	0.0067	0.0105	0.89
11	0.0009	0.0011	0.0012	0.0012	0.0004	0.0004	0.06
12	0.0005	0.0004	0.0006	0.0003	0.0004	0.0004	0.20

Table 6: Nonzero average of glove sensor results comparing left and right by sensor. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 7 provides the statistical significance of sensor to sensor comparisons for the average of both hands and provides several observations worthy of discussion. Sensors 3, 5, and 7, distal sensors on the fingers, measure the highest pressures. Sensor 3 has high pressures associated with it, which are significantly higher than most of the others except for sensors 5 and 7. These latter two sensors also indicate high pressures. Sensors 11, 12, and 2 provide the lowest measured pressures of all the sensors. Sensors 11 and 12 are located on the fifth metacarpal. Sensor 2 is the proximal sensor on the thumb. Sensor 12 has significantly lower pressures than everything except for sensor 11. Sensor 11 has significantly lower pressures than everything except for sensor 12 and 2. Sensor 2 is significantly lower than the whole hand and sensors 3, 5, 6, 7, 8, 9 and 10.

T-Tests	*Whole Hand*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Whole Hand		0.09	0.01	1.2E-08	0.12	0.01	0.30	0.01	0.38	0.88	0.81	2.0E-04	9.3E-04
1	0.09		0.11	2.9E-04	0.69	1.8E-04	0.22	7.7E-04	0.25	0.07	0.14	3.4E-04	7.6E-04
2	0.01	0.11		6.5E-05	0.06	3.2E-06	1.2E-03	3.2E-05	0.01	1.6E-03	0.01	0.05	0.04
3	1.2E-08	2.9E-04	6.5E-05		1.3E-04	0.06	3.0E-04	0.07	3.9E-04	1.1E-03	2.7E-03	1.1E-05	1.4E-04
4	0.12	0.69	0.06	1.3E-04		2.9E-04	0.52	9.8E-04	0.46	0.14	0.24	5.5E-04	1.4E-03
5	0.01	1.8E-04	3.2E-06	0.06	2.9E-04		4.5E-04	0.97	2.0E-03	0.01	0.02	1.3E-08	5.3E-07
6	0.30	0.22	1.2E-03	3.0E-04	0.52	4.5E-04		1.8E-03	0.80	0.26	0.40	1.3E-10	2.3E-09
7	0.01	7.7E-04	3.2E-05	0.07	9.8E-04	0.97	1.8E-03		0.01	0.03	0.04	4.8E-07	9.8E-06
8	0.38	0.25	0.01	3.9E-04	0.46	2.0E-03	0.80	0.01		0.45	0.57	2.1E-05	1.1E-04
9	0.88	0.07	1.6E-03	1.1E-03	0.14	0.01	0.26	0.03	0.45		0.92	3.3E-06	2.8E-05
10	0.81	0.14	0.01	2.7E-03	0.24	0.02	0.40	0.04	0.57	0.92		1.1E-04	5.0E-04
11	2.0E-04	3.4E-04	0.05	1.1E-05	5.5E-04	1.3E-08	1.3E-10	4.8E-07	2.1E-05	3.3E-06	1.1E-04		0.09
12	9.3E-04	7.6E-04	0.04	1.4E-04	1.4E-03	5.3E-07	2.3E-09	9.8E-06	1.1E-04	2.8E-05	5.0E-04	0.09	

Table 7: Nonzero average of glove sensor results comparing sensors for the average of both hands. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 8 compares the significance among nonzero pressures for sensors on the left hand. The highest pressures are associated with sensors 3, 5 and 7. Sensor 3 indicates significantly higher pressures than all others. Sensors 5 and 7 measure significantly higher pressures than sensors 2, 8, 11, and 12. Sensors 11, 12, and 2 indicate the lowest pressures. The pressures with sensor 11 are significantly lower than most, except for sensors 2 and 12. Sensor 12 indicates significantly lower pressures except for the whole hand and sensor 11. Sensor 2 is significantly lower than the whole hand and sensor 1, 3, 4, 5, 6, 7, 8, 9, and 10.

T-Tests	***Whole Hand***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Whole Hand		0.52	0.03	1.4E-09	0.59	0.51	0.86	0.86	0.21	0.50	0.75	4.1E-03	0.06
1	0.52		0.02	3.9E-03	0.84	0.16	0.50	0.28	0.60	0.90	0.65	2.4E-03	0.04
2	0.03	0.02		1.3E-03	0.02	2.4E-04	1.4E-06	2.2E-05	0.01	3.1E-03	6.7E-04	0.63	0.03
3	2.6E-02	3.9E-03	1.3E-03		1.4E-03	3.0E-03	3.9E-03	1.5E-03	2.3E-04	5.9E-04	2.4E-03	6.3E-05	0.01
4	1.4E-09	0.84	0.02	1.4E-03		0.23	0.71	0.42	0.45	0.91	0.83	3.8E-03	0.05
5	0.59	0.16	2.4E-04	3.0E-03	0.23		0.31	0.55	0.02	0.12	0.27	4.6E-06	2.1E-03
6	0.51	0.50	1.4E-06	3.9E-03	0.71	0.31		0.57	0.11	0.52	0.85	5.8E-09	3.2E-05
7	0.86	0.28	2.2E-05	1.5E-03	0.42	0.55	0.57		0.04	0.25	0.49	1.7E-07	3.1E-04
8	0.86	0.60	0.01	2.3E-04	0.45	0.02	0.11	0.04		0.42	0.22	4.6E-04	0.01
9	0.21	0.90	3.1E-03	5.9E-04	0.91	0.12	0.52	0.25	0.42		0.69	1.8E-04	0.01
10	0.50	0.65	6.7E-04	2.4E-03	0.83	0.27	0.85	0.49	0.22	0.69		2.1E-05	3.6E-03
11	4.1E-03	2.4E-03	0.63	6.3E-05	3.8E-03	4.6E-06	5.8E-09	1.7E-07	4.6E-04	1.8E-04	2.1E-05		0.26
12	0.06	0.04	0.03	0.01	0.05	2.1E-03	3.2E-05	3.1E-04	0.01	0.01	3.6E-03	0.26	

Table 8: Nonzero average of glove sensor results comparing sensors for the left hand. A light green t-test cell indicates that the compared values are significantly different.

Table 9 presents a comparative analysis of the statistical significance of measurements from the sensors on the right hand. Sensors 7, 5, and 3 indicate the highest pressures. Sensor 5 is associated with significantly higher pressures than the whole hand and sensors 1, 2, 4, 6, 8, 10, 11, and 12. Sensor 3 has significantly higher pressures than sensors 1, 2, 4, 6, 11, and 12. Sensors 12, 11, and 1 indicate the lowest pressures. Sensors 11 and 12 have significantly the same pressures. Sensor 12 has significantly lower pressures than the whole hand and sensors 1, 3, 4, 5, 6, 7, 8, 9, and 10. Sensor 11 has significantly lower pressures than the whole hand and sensors 1, 3, 4, 5, 6, 7, 8, and 9. Sensor 10 has significantly the same pressure as the average of the whole hand. Sensors 2 and 4 have significantly the same pressures and are both proximal sensors.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.06	0.09	0.30	0.06	6.3E-04	0.19	1.1E-04	0.86	0.56	1.00	0.02	4.9E-03
1	0.06		0.76	8.9E-05	0.68	2.0E-04	0.09	9.7E-04	0.03	0.01	0.13	1.9E-03	3.7E-04
2	0.09	0.76		4.2E-03	0.95	7.9E-04	0.47	2.1E-03	0.10	0.05	0.23	0.12	0.07
3	0.30	8.9E-05	4.2E-03		1.6E-04	0.07	1.4E-03	0.06	0.44	0.69	0.46	1.3E-05	6.7E-07
4	0.06	0.68	0.95	1.6E-04		1.2E-04	0.22	5.5E-04	0.04	0.02	0.15	0.01	1.4E-03
5	6.3E-04	2.0E-04	7.9E-04	0.07	1.2E-04		3.3E-04	0.71	0.04	0.06	0.05	4.6E-04	5.6E-05
6	0.19	0.09	0.47	1.4E-03	0.22	3.3E-04		1.1E-03	0.13	0.06	0.31	1.0E-04	8.9E-06
7	1.1E-04	9.7E-04	2.1E-03	0.06	5.5E-04	0.71	1.1E-03		0.04	0.05	0.05	2.5E-03	4.7E-04
8	0.86	0.03	0.10	0.44	0.04	0.04	0.13	0.04		0.76	0.91	0.01	2.7E-03
9	0.56	0.01	0.05	0.69	0.02	0.06	0.06	0.05	0.76		0.71	0.01	1.2E-03
10	1.00	0.13	0.23	0.46	0.15	0.05	0.31	0.05	0.91	0.71		0.06	0.03
11	0.02	1.9E-03	0.12	1.3E-05	0.01	4.6E-04	1.0E-04	2.5E-03	0.01	0.01	0.06		0.97
12	4.9E-03	3.7E-04	0.07	6.7E-07	1.4E-03	5.6E-05	8.9E-06	4.7E-04	2.7E-03	1.2E-03	0.03	0.97	

Table 9: Nonzero average of glove sensor results comparing sensors for the right hand. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

The pressures for the hand regions are also compared to aid in understanding of the patterns in the data. The distal region includes sensors 1, 3, 5, 7, and 9. The proximal includes sensors 2, 4, 6, 8, and 10. The fifth metacarpal (located on the palm under the little finger) has sensors 11 and 12, the thumb has sensors 1 and 2, the index finger has sensors 3 and 4, the middle finger has sensors 5 and 6, the ring finger has sensors 7 and 8, and the little finger has sensors 9 and 10. Table 10 shows that distal region tends to produce much higher pressures than the proximal region. For both hands, the index finger, distal region, and ring finger tend to produce the highest pressures, and the fifth metacarpal, thumb, and proximal region tend to produce the lowest pressures.

For the left hand, the highest pressures tend to be found on the index finger, distal region, and middle finger and the lowest on the fifth metacarpal, thumb, and proximal region. For the right hand, the highest pressures are found on the ring finger, distal region, and middle finger and the lowest on the fifth metacarpal, thumb, and proximal region. The left hand tends to exert higher pressures than the right hand in general with significantly higher pressures evident on the fifth metacarpal and index finger; but the ring finger on right hand produces significantly higher pressures than the left.

Region	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	Left Versus Right T-Test
Whole Hand	0.0072	0.0097	0.0078	0.0107	0.0067	0.0085	0.20
Distal	0.0102	0.0118	0.0108	0.0135	0.0095	0.0097	0.37
Proximal	0.0054	0.0063	0.0058	0.0058	0.0050	0.0067	0.32
Fifth Metacarpal	0.0007	0.0009	0.0010	0.0011	0.0004	0.0004	0.01
Thumb	0.0036	0.0052	0.0041	0.0058	0.0032	0.0047	0.48
Index	0.0108	0.0151	0.0152	0.0194	0.0060	0.0050	1.6E-03
Middle	0.0085	0.0075	0.0084	0.0060	0.0087	0.0088	0.80
Ring	0.0086	0.0091	0.0067	0.0052	0.0107	0.0117	0.02
Little	0.0070	0.0076	0.0067	0.0058	0.0072	0.0092	0.71

Table 10: Nonzero average of glove sensor results comparing left and right by region. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 11 compares the statistical significance of measurements on a region by region basis for both hands. The index finger and distal region exert significantly higher pressures than the whole hand, proximal region, fifth metacarpal, thumb, and little finger. The ring finger provides significantly higher pressures than the proximal region, the fifth metacarpal, and the thumb and provides significantly the same pressures as the middle finger. The fifth metacarpal tends to produce significantly lower pressures than everything else. The thumb also exerts significantly lower pressures than everything except for the fifth metacarpal. The proximal region provides significantly lower pressures like the thumb and fifth metacarpal.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		1.5E-04	2.7E-12	7.4E-07	1.7E-03	1.8E-03	0.19	0.19	0.79
Distal	1.5E-04		6.1E-08	6.4E-09	4.6E-06	0.69	0.18	0.20	0.01
Proximal	2.7E-12	6.1E-08		8.2E-08	0.03	5.7E-06	8.3E-05	2.4E-04	0.05
Fifth Metacarpal	7.4E-07	6.4E-09	8.2E-08		8.0E-05	1.7E-06	1.3E-12	1.4E-09	8.0E-09
Thumb	1.7E-03	4.6E-06	0.03	8.0E-05		1.2E-04	2.6E-06	3.7E-05	1.4E-03
Index	1.8E-03	0.69	5.7E-06	1.7E-06	1.2E-04		0.17	0.19	0.02
Middle	0.19	0.18	8.3E-05	1.3E-12	2.6E-06	0.17		0.99	0.13
Ring	0.19	0.20	2.4E-04	1.4E-09	3.7E-05	0.19	0.99		0.17
Little	0.79	0.01	0.05	8.0E-09	1.4E-03	0.02	0.13	0.17	

Table 11: Nonzero average of glove sensor results comparing regions for both hands. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 12 compares the significance of results for regions and fingers on the left hand. The index finger produces significantly higher pressures than everything except for the distal region. The distal region has significantly higher pressures than the whole hand, proximal region, fifth metacarpal, thumb, ring finger, and little finger. The pressures exerted by the middle finger are significantly higher than the proximal region, fifth metacarpal, and thumb but are significantly lower than the index finger. The fifth metacarpal has significantly lower pressures than everything else. The thumb has significantly lower pressures than everything else except for the fifth metacarpal, which it has significantly higher pressures than, and the proximal region. The proximal region has significantly lower pressures than the distal region, index finger, and middle finger and significantly higher pressures than the fifth metacarpal. The ring and little fingers have significantly the same pressures.

T-Tests	*Whole Hand*	*Distal*	*Proximal*	*Fifth Metacarpal*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*
Whole Hand		0.01	0.07	6.4E-04	0.05	7.5E-05	0.69	0.46	0.48
Distal	0.01		3.1E-04	1.1E-04	0.01	0.08	0.21	0.03	0.03
Proximal	0.07	3.1E-04		1.5E-05	0.14	5.6E-06	0.01	0.35	0.38
Fifth Metacarpal	6.4E-04	1.1E-04	1.5E-05		0.01	1.5E-04	3.8E-09	9.5E-08	9.6E-07
Thumb	0.05	0.01	0.14	0.01		2.0E-03	1.9E-03	0.03	0.05
Index	7.5E-05	0.08	5.6E-06	1.5E-04	2.0E-03		0.02	1.9E-03	3.4E-03
Middle	0.69	0.21	0.01	3.8E-09	1.9E-03	0.02		0.12	0.15
Ring	0.46	0.03	0.35	9.5E-08	0.03	1.9E-03	0.12		1.00
Little	0.48	0.03	0.38	9.6E-07	0.05	3.4E-03	0.15	1.00	

Table 12: Nonzero average of glove sensor results comparing regions for the left hand. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 13 compares the significance of pressure relationships for regions and fingers on the right hand. The pressures from the ring finger are statistically higher than the whole hand, proximal region, fifth metacarpal, thumb, and index finger. The distal region provides significantly higher pressures than the whole hand, proximal region, fifth metacarpal, thumb, and index finger. The middle finger produces significantly higher pressures than the proximal region, fifth metacarpal, and thumb. The fifth metacarpal has pressures that are statistically lower than everything else. The thumb has significantly lower pressures than everything else, except for the fifth metacarpal, which it has significantly higher pressures than, and the proximal region. The proximal region is associated with significantly lower pressures than the distal region, fifth metacarpal, middle finger, and ring finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		3.3E-03	0.06	2.3E-04	0.01	0.59	0.11	4.3E-03	0.68
Distal	3.3E-03		3.8E-05	4.6E-06	9.8E-05	0.02	0.60	0.49	0.16
Proximal	0.06	3.8E-05		7.6E-04	0.13	0.33	2.6E-03	1.1E-04	0.08
Fifth Metacarpal	2.3E-04	4.6E-06	7.6E-04		3.4E-03	3.2E-07	7.9E-06	2.9E-05	3.2E-04
Thumb	0.01	9.8E-05	0.13	3.4E-03		0.01	4.8E-04	2.3E-04	0.01
Index	0.59	0.02	0.33	3.2E-07	0.01		0.06	0.01	0.41
Middle	0.11	0.60	2.6E-03	7.9E-06	4.8E-04	0.06		0.33	0.41
Ring	4.3E-03	0.49	1.1E-04	2.9E-05	2.3E-04	0.01	0.33		0.11
Little	0.68	0.16	0.08	3.2E-04	0.01	0.41	0.41	0.11	

Table 13: Nonzero average of glove sensor results comparing regions for the right hand. A light green t-test cell indicates that the compared values are significantly different.

The next set of results compares nonzero pressure patterns for the residents and staff separately. Table 14 provides the sensor by sensor comparisons for the average of both hands, the left hand, and the right hand. For average of both hands, specifically the whole hand, the residents apply significantly higher pressures than the staff. This result is probably influenced by sensor 3, where the residents apply significantly higher pressures than the staff members. There are no other significant relationships for the average of both hands. The left and right hands considered on their own show no significant relationship.

Sensor		Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Nonzero Average Pressure (Psi)	STDEV.S	T-Test
Whole Hand	Residents (5)	0.0081	0.0109	0.02	0.0088	0.0121	0.06	0.0073	0.0094	0.18
	Staff (4)	0.0061	0.0077		0.0063	0.0082		0.0059	0.0072	
1	Residents (5)	0.0054	0.0068	0.23	0.0081	0.0088	0.17	0.0030	0.0030	0.94
	Staff (4)	0.0033	0.0018		0.0035	0.0021		0.0031	0.0016	
2	Residents (5)	0.0019	0.0021	0.44	0.0011	0.0006	0.31	0.0024	0.0025	0.47
	Staff (4)	0.0032	0.0063		0.0015	0.0009		0.0044	0.0082	
3	Residents (5)	0.0203	0.0209	0.05	0.0292	0.0246	0.08	0.0094	0.0060	0.35
	Staff (4)	0.0106	0.0133		0.0138	0.0182		0.0074	0.0041	
4	Residents (5)	0.0057	0.0075	0.38	0.0075	0.0094	0.48	0.0036	0.0038	0.61
	Staff (4)	0.0040	0.0044		0.0050	0.0058		0.0029	0.0022	
5	Residents (5)	0.0118	0.0097	0.34	0.0098	0.0066	0.51	0.0140	0.0121	0.45
	Staff (4)	0.0095	0.0080		0.0080	0.0080		0.0109	0.0080	
6	Residents (5)	0.0065	0.0036	0.09	0.0080	0.0031	0.27	0.0051	0.0035	0.20
	Staff (4)	0.0047	0.0035		0.0062	0.0046		0.0036	0.0021	
7	Residents (5)	0.0131	0.0123	0.07	0.0094	0.0052	0.10	0.0172	0.0164	0.16
	Staff (4)	0.0080	0.0065		0.0084	0.0048		0.0097	0.0077	
8	Residents (5)	0.0065	0.0069	0.57	0.0056	0.0046	0.66	0.0076	0.0091	0.70
	Staff (4)	0.0054	0.0059		0.0047	0.0055		0.0063	0.0064	
9	Residents (5)	0.0057	0.0046	0.12	0.0049	0.0047	0.12	0.0067	0.0045	0.48
	Staff (4)	0.0087	0.0090		0.0084	0.0070		0.0089	0.0109	
10	Residents (5)	0.0070	0.0086	0.89	0.0055	0.0050	0.13	0.0089	0.0116	0.34
	Staff (4)	0.0067	0.0081		0.0091	0.0060		0.0045	0.0094	
11	Residents (5)	0.0008	0.0004	0.38	0.0008	0.0003	0.18	0.0006	0.0005	0.29
	Staff (4)	0.0011	0.0015		0.0016	0.0018		0.0003	0.0002	
12	Residents (5)	0.0006	0.0004	0.10	0.0007	0.0003	0.42	0.0005	0.0004	0.10
	Staff (4)	0.0003	0.0002		0.0005	0.0001		0.0001	0.0001	

Table 14: Comparison of average nonzero pressures for the residents and staff subjects sensor by sensor for the average of both hands, the left hand, and the right hand. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 15 compares the nonzero pressures measured for residents and staff on a region by region basis. For the average of both hands, the residents apply significantly higher pressures in the distal region than the staff members do, suggesting that perhaps the staff learn from experience to apply more even pressures using their whole hands. For the left hand only, the staff members apply significantly higher pressures with the little finger than the residents do, also suggesting that the staff may learn through experience to make better use of the whole hand. Considering only the right hand, the resident apply significantly higher pressures on the fifth metacarpal, but the overall pressure applied on the fifth metacarpal is still very low, only 0.0005 MPa.

Region		Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Left Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Right Nonzero Average Pressure (Psi)	STDEV.S	T-Test
Whole Hand	**Residents (5)**	0.0081	0.0109	0.02	0.0088	0.0121	0.06	0.0073	0.0094	0.18
	Staff (4)	0.0061	0.0077		0.0063	0.0082		0.0059	0.0072	
Distal	**Residents (5)**	0.0116	0.0134	0.03	0.0127	0.0152	0.06	0.0105	0.0111	0.23
	Staff (4)	0.0083	0.0090		0.0083	0.0102		0.0084	0.0076	
Proximal	**Residents (5)**	0.0058	0.0065	0.25	0.0061	0.0061	0.52	0.0055	0.0070	0.36
	Staff (4)	0.0049	0.0059		0.0054	0.0054		0.0044	0.0064	
Fifth Metacarpal	**Residents (5)**	0.0007	0.0004	0.46	0.0008	0.0003	0.20	0.0005	0.0004	0.05
	Staff (4)	0.0009	0.0013		0.0013	0.0016		0.0002	0.0002	
Thumb	**Residents (5)**	0.0040	0.0056	0.55	0.0056	0.0078	0.13	0.0027	0.0027	0.45
	Staff (4)	0.0032	0.0048		0.0025	0.0019		0.0038	0.0063	
Index	**Residents (5)**	0.0128	0.0172	0.09	0.0183	0.0214	0.12	0.0064	0.0057	0.53
	Staff (4)	0.0077	0.0109		0.0100	0.0147		0.0055	0.0040	
Middle	**Residents (5)**	0.0094	0.0080	0.17	0.0091	0.0054	0.30	0.0097	0.0100	0.35
	Staff (4)	0.0073	0.0068		0.0073	0.0067		0.0074	0.0069	
Ring	**Residents (5)**	0.0099	0.0106	0.07	0.0076	0.0052	0.14	0.0128	0.0141	0.17
	Staff (4)	0.0067	0.0063		0.0055	0.0051		0.0081	0.0072	
Little	**Residents (5)**	0.0063	0.0067	0.35	0.0051	0.0047	0.03	0.0076	0.0083	0.76
	Staff (4)	0.0077	0.0085		0.0087	0.0064		0.0068	0.0102	

Table 15: Comparison of the residents and staff region by region for the average of both hands, the left hand, and the right hand. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Overall, the fingers tend to apply more pressure than the palm and thumb. The distal region of the hand tends to apply more pressure than the proximal region, suggesting that the fingertips apply more of the pressure than the main body of the hand. The residents and staff are generally not significantly different.

Part 2.2 - Excessive Force

Table 16 compares the average pressures for both hand, the left hand, and the right hand for each sensor and also compares the left and right for significant differences. The left hand tends to have higher pressures, but this trend is never significant. On sensor 2, the left and right hand have significantly the same pressure values. On sensor 7, the right hand has significantly higher pressure values.

Sensor	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	Left Versus Right T-Test
Whole Hand	0.0087	0.0100	0.0093	0.0096	0.0079	0.0104	0.33
1	0.0069	0.0085	0.0096	0.0106	0.0039	0.0043	0.18
2	0.0034	0.0031	0.0034	0.0042	0.0034	0.0019	0.99
3	0.0127	0.0113	0.0161	0.0141	0.0089	0.0057	0.17
4	0.0056	0.0043	0.0064	0.0046	0.0044	0.0038	0.39
5	0.0130	0.0098	0.0133	0.0106	0.0128	0.0095	0.93
6	0.0104	0.0078	0.0125	0.0090	0.0081	0.0061	0.30
7	0.0158	0.0140	0.0093	0.0053	0.0230	0.0172	0.03
8	0.0057	0.0063	0.0078	0.0074	0.0033	0.0039	0.12
9	0.0123	0.0150	0.0111	0.0146	0.0139	0.0165	0.71
10	0.0066	0.0066	0.0093	0.0075	0.0035	0.0038	0.09
11	0.0020	0.0034	0.0031	0.0042	0.0005	0.0007	0.17
12	0.0012	0.0016	0.0026	0.0028	0.0006	0.0006	0.13

Table 16: Average of glove sensor results comparing left and right by sensors. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 17 compares sensor by sensor for both hands. Sensor 7 has significantly higher pressure values than the whole hand and sensors 1, 2, 4, 8, 10, 11, and 12. Sensor 5 has significantly higher pressure values than sensors 2, 4, 8, 10, 11, and 12. Sensor 3 has significantly higher values than sensors 2, 4, 8, 11, and 12. Sensor 11 indicated a significantly lower pressure values than the whole hand, 1, 3, 4, 5, 6, 7, 9, and 10. Sensor 12 indicates a significantly lower pressure value than the whole hand, 3, 4, 5, 6, 7, and 10. Sensor 2 provides a significantly lower value than the whole hand, 3, 5, 6, 7, and 9. The pressures at sensors 4 and 8 are significantly the same, and both are proximal sensors on the fingers.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.48	0.04	0.10	0.25	0.06	0.50	4.6E-03	0.20	0.16	0.42	0.01	0.05
1	0.48		0.15	0.09	0.61	0.05	0.23	0.03	0.62	0.20	0.90	0.05	0.10
2	0.04	0.15		4.1E-03	0.12	8.6E-04	3.2E-03	2.1E-03	0.21	0.03	0.11	0.26	0.09
3	0.10	0.09	4.1E-03		0.03	0.93	0.51	0.46	0.02	0.93	0.07	1.3E-03	0.01
4	0.25	0.61	0.12	0.03		0.01	0.05	0.01	0.98	0.11	0.65	0.02	0.02
5	0.06	0.05	8.6E-04	0.93	0.01		0.40	0.48	0.01	0.86	0.03	2.2E-04	4.1E-03
6	0.50	0.23	3.2E-03	0.51	0.05	0.40		0.19	0.06	0.67	0.15	7.1E-04	0.01
7	4.6E-03	0.03	2.1E-03	0.46	0.01	0.48	0.19		0.01	0.47	0.02	7.8E-04	0.01
8	0.20	0.62	0.21	0.02	0.98	0.01	0.06	0.01		0.09	0.69	0.05	0.08
9	0.16	0.20	0.03	0.93	0.11	0.86	0.67	0.47	0.09		0.18	0.01	0.07
10	0.42	0.90	0.11	0.07	0.65	0.03	0.15	0.02	0.69	0.18		0.03	0.05
11	0.01	0.05	0.26	1.3E-03	0.02	2.2E-04	7.1E-04	7.8E-04	0.05	0.01	0.03		0.53
12	0.05	0.10	0.09	0.01	0.02	4.1E-03	0.01	0.01	0.08	0.07	0.05	0.53	

Table 17: Both hands sensor by sensor comparison. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 18 examines the significance of left hand results sensor by sensor. Values recorded by sensor 3 are significantly higher than the whole hand and sensors 2 and 11. Sensors 5 and 6 indicated significantly higher pressures than sensors 2 and 11. Sensor 12 provides the lowest values, but that outcome is not significant relative to any other sensors. Pressures measured at sensor 11 are significantly lower than the whole hand and sensors 3, 5, 6, 7, and 10. Sensor 2 provided significantly lower pressures than sensors 3, 5, 6, and 7. The whole hand's average is significantly the same as sensors 7 and 10. Sensor 1 indicates significantly the same pressures as sensors 7 and 10.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.94	0.11	0.04	0.38	0.22	0.37	1.00	0.63	0.60	0.99	0.05	0.33
1	0.94		0.17	0.27	0.43	0.46	0.55	0.95	0.68	0.80	0.95	0.11	0.40
2	0.11	0.17		0.04	0.20	0.04	0.03	0.03	0.18	0.20	0.09	0.87	0.82
3	0.04	0.27	0.04		0.07	0.61	0.53	0.17	0.12	0.44	0.23	0.02	0.22
4	0.38	0.43	0.20	0.07		0.09	0.10	0.23	0.64	0.37	0.36	0.12	0.30
5	0.22	0.46	0.04	0.61	0.09		0.87	0.31	0.20	0.71	0.38	0.02	0.20
6	0.37	0.55	0.03	0.53	0.10	0.87		0.37	0.25	0.82	0.45	0.01	0.18
7	1.00	0.95	0.03	0.17	0.23	0.31	0.37		0.61	0.72	0.99	0.01	0.12
8	0.63	0.68	0.18	0.12	0.64	0.20	0.25	0.61		0.54	0.69	0.11	0.37
9	0.60	0.80	0.20	0.44	0.37	0.71	0.82	0.72	0.54		0.75	0.13	0.45
10	0.99	0.95	0.09	0.23	0.36	0.38	0.45	0.99	0.69	0.75		0.05	0.27
11	0.05	0.11	0.87	0.02	0.12	0.02	0.01	0.01	0.11	0.13	0.05		0.90
12	0.33	0.40	0.82	0.22	0.30	0.20	0.18	0.12	0.37	0.45	0.27	0.90	

Table 18: Left hand sensor by sensor comparison. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Moving to comparisons for the right hand, Table 19 provides sensor by sensor comparisons. Average pressures for sensor 7 are significantly higher than others except for sensors 5 and 9. Sensor 9, while indicating the second highest nonzero average pressure value after sensor 7, is not significantly comparable to any other sensor. Sensor 5 indicated significantly higher pressures than sensors 1, 2, 8, 10, 11, and 12. Sensor 11 has significantly lower pressures than sensors 2, 3, 4, 5, 6, and 7. Sensor 12 has significantly lower pressure values than sensors 2, 3, 5, 6, and 7. Sensor 8, the third lowest, somewhat unusually, measures significantly lower pressure values than sensors 3, 5, and 7.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.29	0.23	0.77	0.42	0.16	0.96	1.9E-04	0.19	0.15	0.26	0.09	0.12
1	0.29		0.77	0.06	0.83	0.03	0.14	0.01	0.75	0.12	0.83	0.08	0.11
2	0.23	0.77		0.02	0.54	0.01	0.06	0.01	0.93	0.10	0.99	4.5E-03	0.01
3	0.77	0.06	0.02		0.12	0.30	0.79	0.03	0.03	0.41	0.05	3.7E-03	0.01
4	0.42	0.83	0.54	0.12		0.06	0.23	0.02	0.59	0.20	0.66	0.04	0.06
5	0.16	0.03	0.01	0.30	0.06		0.27	0.12	0.01	0.87	0.03	0.01	0.01
6	0.96	0.14	0.06	0.79	0.23	0.27		0.05	0.07	0.40	0.11	0.01	0.02
7	1.9E-04	0.01	0.01	0.03	0.02	0.12	0.05		4.1E-03	0.28	0.01	0.01	0.01
8	0.19	0.75	0.93	0.03	0.59	0.01	0.07	4.1E-03		0.08	0.94	0.11	0.15
9	0.15	0.12	0.10	0.41	0.20	0.87	0.40	0.28	0.08		0.13	0.07	0.10
10	0.26	0.83	0.99	0.05	0.66	0.03	0.11	0.01	0.94	0.13		0.09	0.13
11	0.09	0.08	4.5E-03	3.7E-03	0.04	0.01	0.01	0.01	0.11	0.07	0.09		0.90
12	0.12	0.11	0.01	0.01	0.06	0.01	0.02	0.01	0.15	0.10	0.13	0.90	

Table 19: Right hand sensor by sensor comparison. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 20 compares the nonzero average pressures from the left and right glove sensor region by region. While the left hand tends to produce higher pressure values than the right hand, there are few significant relationships. The left hand applies significantly higher pressures with the proximal region, suggesting a less fingertip-oriented behavior. The left and right hands apply significantly the same pressure with the middle finger.

Region	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	Left Versus Right T-Test
Whole Hand	0.0087	0.0100	0.0093	0.0096	0.0079	0.0104	0.33
Distal	0.0123	0.0121	0.0119	0.0114	0.0127	0.0129	0.76
Proximal	0.0063	0.0062	0.0080	0.0071	0.0045	0.0043	0.01
Fifth Metacarpal	0.0018	0.0029	0.0030	0.0038	0.0006	0.0006	0.50
Thumb	0.0053	0.0067	0.0069	0.0088	0.0037	0.0032	0.07
Index	0.0096	0.0095	0.0115	0.0116	0.0071	0.0054	0.07
Middle	0.0119	0.0090	0.0129	0.0096	0.0109	0.0084	0.99
Ring	0.0107	0.0119	0.0086	0.0063	0.0132	0.0158	0.21
Little	0.0097	0.0121	0.0103	0.0117	0.0090	0.0131	0.16

Table 20: Average of glove sensor results comparing left and right by regions. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

The next three tables show the significance of pressures on a region by region basis for both hands, the left hand only, and the right hand only. Table 21 shows the results for both hands. The distal region produces significantly higher pressures than the whole hand, proximal region, fifth metacarpal, and thumb. The middle and ring fingers exert significantly higher pressures than the proximal region, fifth metacarpal, and thumb. The little and index fingers provide significantly the same pressures. The fifth metacarpal is associated with significantly lower pressures than everything else. The thumb creates significantly lower pressures than the distal region, index finger, middle finger, and ring finger. Finally, the proximal region exerts significantly lower pressures than the whole hand, distal region, fifth metacarpal, index finger, middle finger, ring finger, and little finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		0.01	0.05	1.5E-03	0.07	0.61	0.07	0.26	0.59
Distal	0.01		1.0E-04	9.6E-05	2.3E-03	0.24	0.88	0.51	0.29
Proximal	0.05	1.0E-04		1.2E-03	0.43	0.03	1.8E-04	0.01	0.05
Fifth Metacarpal	1.5E-03	9.6E-05	1.2E-03		0.03	4.5E-04	3.9E-06	9.8E-04	4.2E-03
Thumb	0.07	2.3E-03	0.43	0.03		0.04	1.1E-03	0.02	0.07
Index	0.61	0.24	0.03	4.5E-04	0.04		0.30	0.65	0.97
Middle	0.07	0.88	1.8E-04	3.9E-06	1.1E-03	0.30		0.63	0.39
Ring	0.26	0.51	0.01	9.8E-04	0.02	0.65	0.63		0.72
Little	0.59	0.29	0.05	4.2E-03	0.07	0.97	0.39	0.72	

Table 21: Both hands region by region comparison. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

The next set of region by region comparisons is for the left hand (Table 22). The middle finger provides the highest pressures, but these pressures are only significantly higher than the proximal region and the fifth metacarpal. The distal region is associated with significantly higher pressures than the proximal region and fifth metacarpal. The index finger, with the third highest pressures, is only significantly higher than the fifth metacarpal. Pressures for the fifth metacarpal are significantly lower than those observed for the whole hand, distal region, proximal region, index finger, middle finger, and ring finger. The thumb is associated with the second lowest pressures but, they are not significantly related to other regions. The proximal region produces significantly lower pressures than the distal region and the middle finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		0.14	0.41	0.03	0.34	0.37	0.15	0.74	0.71
Distal	0.14		0.05	0.01	0.11	0.90	0.74	0.22	0.60
Proximal	0.41	0.05		0.03	0.63	0.14	0.03	0.74	0.35
Fifth Metacarpal	0.03	0.01	0.03		0.18	0.02	3.1E-03	0.01	0.06
Thumb	0.34	0.11	0.63	0.18		0.19	0.07	0.50	0.35
Index	0.37	0.90	0.14	0.02	0.19		0.70	0.32	0.74
Middle	0.15	0.74	0.03	3.1E-03	0.07	0.70		0.11	0.47
Ring	0.74	0.22	0.74	0.01	0.50	0.32	0.11		0.57
Little	0.71	0.60	0.35	0.06	0.35	0.74	0.47	0.57	

Table 22: Left hand region by region comparison. A light green t-test cell indicates that the compared values are significantly different.

Table 23 presents a similar region by region significance test for the right hand. The average pressures due to the ring finger, which is the highest, and that for the middle finger, which is the third highest, are significantly higher than the average pressures produced by the proximal region, fifth metacarpal, and thumb. The distal region provides the second highest pressures, which is significantly higher than the whole hand, proximal region, fifth metacarpal, and thumb. The fifth metacarpal provides significantly lower pressures than everywhere else except for the little finger. The thumb produces a significantly lower average pressure than the distal region, fifth metacarpal, index finger, middle finger, and ring finger. The proximal region is associated significantly lower pressures than the whole hand, distal region, middle finger, and ring finger.

T-Tests	*Whole Hand*	*Distal*	*Proximal*	*Fifth Metacarpal*	*Thumb*	*Index*	*Middle*	*Ring*	*Little*
Whole Hand		0.02	0.05	0.02	0.11	0.77	0.27	0.08	0.72
Distal	0.02		3.9E-04	3.2E-03	0.01	0.11	0.60	0.90	0.35
Proximal	0.05	3.9E-04		4.4E-03	0.52	0.06	4.2E-04	2.7E-03	0.06
Fifth Metacarpal	0.02	3.2E-03	4.4E-03		4.0E-03	0.04	2.9E-03	0.02	0.12
Thumb	0.11	0.01	0.52	4.0E-03		0.04	2.9E-03	0.02	0.12
Index	0.77	0.11	0.06	0.04	0.04		0.15	0.17	0.61
Middle	0.27	0.60	4.2E-04	2.9E-03	2.9E-03	0.15		0.60	0.63
Ring	0.08	0.90	2.7E-03	0.02	0.02	0.17	0.60		0.42
Little	0.72	0.35	0.06	0.12	0.12	0.61	0.42	0.42	

Table 23: Right hand region by region comparison. A light green t-test cell indicates that the compared values are significantly different.

Table 24 parses the data to compare the significance of average pressures attributed to residents and staff as the average of both hands, the left hand, and the right hand. Inspection of the table indicates few significant relationships. The staff members apply significantly higher pressures than the residents for the average of the left hand. The staff members appear more willing to show off bad procedure to facilitate learning, whereas the residents perhaps are more reserved and conservative. The residents and staff apply significantly the same pressures for the right hand.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Residents (6)**	0.0078	0.0093	0.18	0.0077	0.0080	0.03	0.0080	0.0107	0.98
	Staff (4)	0.0098	0.0108		0.0117	0.0112		0.0079	0.0103	
1	**Residents (6)**	0.0046	0.0037	0.26	0.0064	0.0038	0.36	0.0024	0.0025	0.36
	Staff (4)	0.0094	0.0117		0.0135	0.0157		0.0054	0.0055	
2	**Residents (6)**	0.0038	0.0035	0.59	0.0044	0.0047	0.37	0.0030	0.0007	0.59
	Staff (4)	0.0029	0.0026		0.0009	0.0001		0.0038	0.0028	
3	**Residents (6)**	0.0148	0.0140	0.37	0.0217	0.0158	0.14	0.0065	0.0048	0.16
	Staff (4)	0.0099	0.0057		0.0078	0.0055		0.0120	0.0058	
4	**Residents (6)**	0.0070	0.0044	0.08	0.0080	0.0045	0.15	0.0054	0.0045	0.41
	Staff (4)	0.0029	0.0024		0.0032	0.0033		0.0024	0.0006	
5	**Residents (6)**	0.0107	0.0073	0.19	0.0106	0.0059	0.36	0.0107	0.0090	0.42
	Staff (4)	0.0166	0.0123		0.0173	0.0156		0.0160	0.0105	
6	**Residents (6)**	0.0107	0.0068	0.87	0.0107	0.0074	0.52	0.0107	0.0071	0.23
	Staff (4)	0.0100	0.0099		0.0154	0.0124		0.0047	0.0025	
7	**Residents (6)**	0.0140	0.0159	0.53	0.0073	0.0029	0.15	0.0221	0.0218	0.87
	Staff (4)	0.0183	0.0114		0.0124	0.0071		0.0242	0.0126	
8	**Residents (6)**	0.0051	0.0045	0.62	0.0057	0.0044	0.28	0.0043	0.0050	0.41
	Staff (4)	0.0065	0.0084		0.0111	0.0104		0.0020	0.0014	
9	**Residents (6)**	0.0080	0.0119	0.18	0.0032	0.0034	0.03	0.0152	0.0170	0.84
	Staff (4)	0.0177	0.0176		0.0229	0.0175		0.0125	0.0184	
10	**Residents (6)**	0.0042	0.0033	0.14	0.0041	0.0021	0.04	0.0043	0.0046	0.55
	Staff (4)	0.0093	0.0085		0.0144	0.0074		0.0023	0.0029	
11	**Residents (6)**	0.0013	0.0009	0.43	0.0014	0.0010	0.19	0.0010	0.0012	0.23
	Staff (4)	0.0027	0.0046		0.0051	0.0059		0.0003	0.0002	
12	**Residents (6)**	0.0008	0.0005	0.48	0.0007	#DIV/0!	#DIV/0!	0.0008	0.0007	0.38
	Staff (4)	0.0017	0.0025		0.0046	#DIV/0!		0.0003	0.0002	

Table 24: Comparison of the residents and staff sensor by sensor for the average of both hands, the left hand, and the right hand. #DIV/0!) indicates the value was unable to be calculated due to too few data points. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 25 compares the residents and staff region by region in terms of the average pressure for both hands, the left hand, and the right hand. There are few significant relationships. For the left hand, the staff members generated significantly higher pressures with the little finger, something that is seen in previous trials. For the right hand, the residents and staff are significantly the same in terms of the average pressure for the whole hand and the ring finger.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Residents (6)**	0.0078	0.0093	0.18	0.0077	0.0080	0.03	0.0080	0.0107	0.98
	Staff (4)	0.0098	0.0108		0.0117	0.0112		0.0079	0.0103	
Distal	**Residents (5)**	0.0107	0.0117	0.14	0.0100	0.0100	0.27	0.0116	0.0138	0.54
	Staff (4)	0.0144	0.0123		0.0148	0.0129		0.0140	0.0121	
Proximal	**Residents (5)**	0.0062	0.0051	0.80	0.0067	0.0052	0.09	0.0055	0.0051	0.09
	Staff (4)	0.0065	0.0075		0.0100	0.0093		0.0031	0.0022	
Fifth Metacarpal	**Residents (5)**	0.0011	0.0008	0.29	0.0013	0.0009	0.10	0.0009	0.0008	0.09
	Staff (4)	0.0024	0.0041		0.0050	0.0051		0.0003	0.0002	
Thumb	**Residents (5)**	0.0042	0.0035	0.32	0.0054	0.0042	0.41	0.0027	0.0017	0.25
	Staff (4)	0.0066	0.0094		0.0093	0.0138		0.0046	0.0041	
Index	**Residents (5)**	0.0111	0.0111	0.26	0.0149	0.0131	0.10	0.0060	0.0044	0.34
	Staff (4)	0.0072	0.0058		0.0059	0.0050		0.0088	0.0067	
Middle	**Residents (5)**	0.0107	0.0069	0.32	0.0107	0.0063	0.22	0.0107	0.0079	0.92
	Staff (4)	0.0138	0.0115		0.0164	0.0132		0.0112	0.0097	
Ring	**Residents (5)**	0.0095	0.0123	0.47	0.0065	0.0037	0.07	0.0132	0.0176	0.99
	Staff (4)	0.0124	0.0114		0.0117	0.0083		0.0131	0.0145	
Little	**Residents (5)**	0.0063	0.0091	0.08	0.0036	0.0028	2.8E-03	0.0098	0.0129	0.82
	Staff (4)	0.0138	0.0143		0.0186	0.0133		0.0082	0.0142	

Table 25: Comparison of the residents and staff region by region for the average of both hands, the left hand, and the right hand. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Part 2.3 - Full Delivery

The series of results and significance testing presented here in Part 2.3 examines test results where subjects were asked to complete a full delivery. Table 26 summarizes the nonzero average pressure results for both, left, and right hands for the full delivery scenario. The left hand produces significantly higher pressures than the right hand and as do sensors 3, 4, 6, and 11. Only sensor 7 on the right hand indicates a significantly higher pressure than those on the left. These data continue the trend where the left hand generally creates higher pressures than the right.

Sensor	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	Left Versus Right T-Test
Whole Hand	0.0080	0.0092	0.0089	0.0103	0.0070	0.0077	0.02
1	0.0074	0.0109	0.0108	0.0153	0.0044	0.0031	0.07
2	0.0038	0.0036	0.0024	0.0022	0.0046	0.0040	0.07
3	0.0187	0.0143	0.0244	0.0172	0.0125	0.0060	2.0E-03
4	0.0052	0.0052	0.0071	0.0060	0.0028	0.0022	4.7E-03
5	0.0113	0.0077	0.0102	0.0068	0.0125	0.0085	0.27
6	0.0052	0.0041	0.0073	0.0039	0.0031	0.0032	1.6E-04
7	0.0120	0.0075	0.0092	0.0043	0.0151	0.0090	3.5E-03
8	0.0047	0.0032	0.0049	0.0026	0.0044	0.0038	0.62
9	0.0097	0.0115	0.0094	0.0119	0.0100	0.0114	0.86
10	0.0063	0.0056	0.0071	0.0049	0.0053	0.0063	0.25
11	0.0015	0.0023	0.0024	0.0028	0.0004	0.0002	0.01
12	0.0015	0.0028	0.0027	0.0036	0.0003	0.0001	0.06

Table 26: Both, left, and right comparison of full delivery sensor data. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 27 begins the series of significance tests, comparing the average pressures on both hands sensor by sensor. Inspection of the data summary indicates many significant results. Pressures indicated by sensor 3 are significantly higher pressures than everywhere else. Sensor 7 measures a significantly higher nonzero mean pressure than the whole hand and sensors 1, 2, 4, 6, 8, 10, 11, and 12. A significantly higher pressure is evident with sensor 5 than the whole hand and sensors 1, 2, 4, 6, 8, 10, 11, and 12. Sensors 4 and 6 have significantly the same pressures and are both proximal sensors. Sensor 11 and 12 indicate significantly the same pressures that are significantly lower than everywhere else. Sensor 2 indicates significantly lower pressures than the whole hand and sensors 3, 5, 7, 9, and 10.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.71	0.01	1.2E-13	0.05	0.01	0.04	2.0E-03	0.01	0.22	0.21	9.3E-06	2.9E-03
1	0.71		0.07	8.7E-05	0.24	0.04	0.21	0.02	0.11	0.35	0.54	1.2E-03	0.03
2	0.01	0.07		3.0E-08	0.18	4.3E-07	0.10	3.1E-08	0.27	4.4E-03	0.02	9.3E-04	0.02
3	1.2E-13	8.7E-05	3.0E-08		5.1E-08	1.3E-03	9.4E-09	3.6E-03	2.4E-09	6.9E-04	1.4E-07	3.7E-11	3.6E-06
4	0.05	0.24	0.18	5.1E-08		1.9E-05	0.98	1.9E-06	0.53	0.02	0.35	6.2E-05	0.01
5	0.01	0.04	4.3E-07	1.3E-03	1.9E-05		3.7E-06	0.64	2.5E-07	0.38	2.7E-04	7.8E-12	1.3E-06
6	0.04	0.21	0.10	9.4E-09	0.98	3.7E-06		2.4E-07	0.44	0.01	0.30	1.5E-06	6.6E-04
7	2.0E-03	0.02	3.1E-08	3.6E-03	1.9E-06	0.64	2.4E-07		1.1E-08	0.22	3.4E-05	2.4E-13	1.9E-07
8	0.01	0.11	0.27	2.4E-09	0.53	2.5E-07	0.44	1.1E-08		0.01	0.09	1.1E-06	4.5E-04
9	0.22	0.35	4.4E-03	6.9E-04	0.02	0.38	0.01	0.22	0.01		0.07	2.9E-05	4.3E-03
10	0.21	0.54	0.02	1.4E-07	0.35	2.7E-04	0.30	3.4E-05	0.09	0.07		2.2E-06	9.8E-04
11	9.3E-06	1.2E-03	9.3E-04	3.7E-11	6.2E-05	7.8E-12	1.5E-06	2.4E-13	1.1E-06	2.9E-05	2.2E-06		0.98
12	2.9E-03	0.03	0.02	3.6E-06	0.01	1.3E-06	6.6E-04	1.9E-07	4.5E-04	4.3E-03	9.8E-04	0.98	

Table 27: Comparison of both hands sensor by sensor. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 28 provides a sensor by sensor comparison of significance for results from the left hand. Sensor 3 records significantly higher pressures than anywhere else. Unusually, sensor 1 provides the second highest average pressure, but that sensor is only significantly higher than the mean pressures associated with sensor 11. Sensor 5 provides a significantly higher pressure than sensors 2, 8, 11, and 12. Sensors 4 and 10 exhibited significantly the same pressures, and both are proximal sensors. Sensors 2 and 11 produced significantly the same pressures. The average pressure for sensor 11 is significantly lower than the whole hand, 1, 3, 4, 5, 6, 7, 8, 9, and 10. Sensor 12 also is associated with significantly lower values than sensors 3, 4, 5, 6, 7, and 10. The sensor 2 value is significantly lower than the pressure for the whole hand and measured values from sensors 3, 4, 5, 6, 7, 8, 9, and 10.

T-Tests	Whole Hand	1	2	3	4	5	6	7	8	9	10	11	12
Whole Hand		0.45	0.02	0.00	0.53	0.53	0.47	0.88	0.05	0.81	0.40	3.3E-03	0.07
1	0.45		0.06	0.01	0.27	0.85	0.29	0.60	0.06	0.72	0.26	0.01	0.13
2	0.02	0.06		5.3E-05	0.01	2.6E-04	1.5E-04	4.8E-06	0.01	0.04	2.1E-03	0.98	0.81
3	2.4E-11	0.01	5.3E-05		0.00	2.1E-04	1.9E-05	4.6E-05	9.3E-07	4.8E-04	9.8E-06	3.6E-07	7.3E-04
4	0.39	0.27	0.01	1.7E-05		0.09	0.85	0.15	0.10	0.39	0.97	1.5E-03	0.05
5	0.53	0.85	2.6E-04	2.1E-04	0.09		0.08	0.53	6.0E-04	0.77	0.07	7.0E-06	3.4E-03
6	0.47	0.29	1.5E-04	1.9E-05	0.85	0.08		0.12	0.01	0.43	0.87	1.2E-05	3.7E-03
7	0.88	0.60	4.8E-06	4.6E-05	0.15	0.53	0.12		7.6E-05	0.94	0.11	7.6E-08	2.8E-04
8	0.05	0.06	0.01	9.3E-07	0.10	6.0E-04	0.01	7.6E-05		0.07	0.05	2.6E-03	0.06
9	0.81	0.72	0.04	4.8E-04	0.39	0.77	0.43	0.94	0.07		0.38	0.01	0.11
10	0.40	0.26	2.1E-03	9.8E-06	0.97	0.07	0.87	0.11	0.05	0.38		2.1E-04	0.02
11	3.3E-03	0.01	0.98	3.6E-07	1.5E-03	7.0E-06	1.2E-05	7.6E-08	2.6E-03	9.6E-03	2.1E-04		0.79
12	0.07	0.13	0.81	7.3E-04	0.05	3.4E-03	3.7E-03	2.8E-04	0.06	0.11	0.02	0.79	

Table 28: Comparison of the left hand sensor by sensor. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 29 summarizes the test data related to average pressure from the right hand on a sensor by sensor basis. Sensor 7 indicates significantly higher pressures than the whole hand and sensors 1, 2, 4, 6, 8, 10, 11, and 12. Pressures from sensors 3 and 5 are significantly the same and are significantly higher than the whole hand and sensors 1, 2, 4, 6, 8, 10, 11, and 12. Pressures from sensors 1 and 8 are significantly the same. Values associated with sensors 12 and 11 are significantly lower than everywhere else. Unusually, sensor 4 measured the third lowest pressure and provides significantly lower pressures than the whole hand and sensors 1, 3, 5, 7, and 9.

T-Tests	*Whole Hand*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Whole Hand		0.13	0.15	5.8E-04	0.02	5.6E-04	0.02	1.4E-06	0.12	0.09	0.30	3.2E-04	0.01
1	0.13		0.86	1.5E-06	0.05	1.5E-04	0.17	5.1E-06	0.97	0.04	0.58	1.9E-06	3.7E-04
2	0.15	0.86		3.2E-06	0.07	1.8E-04	0.16	5.4E-06	0.84	0.04	0.68	5.2E-05	2.8E-03
3	5.8E-04	1.5E-06	3.2E-06		3.8E-08	0.99	1.8E-08	0.24	2.2E-06	0.33	1.8E-04	1.3E-10	1.0E-06
4	0.02	0.05	0.07	3.8E-08		1.5E-05	0.67	6.4E-07	0.11	0.01	0.10	4.2E-05	2.2E-03
5	5.6E-04	1.5E-04	1.8E-04	0.99	1.5E-05		5.8E-06	0.29	1.5E-04	0.38	1.5E-03	1.5E-04	1.5E-04
6	0.02	0.17	0.16	1.8E-08	0.67	5.8E-06		1.4E-07	0.23	0.01	0.14	7.3E-04	0.01
7	1.4E-06	5.1E-06	5.4E-06	0.24	6.4E-07	0.29	1.4E-07		4.8E-06	0.09	7.4E-05	1.9E-08	2.6E-05
8	0.12	0.97	0.84	2.2E-06	0.11	1.5E-04	0.23	4.8E-06		0.03	0.57	7.0E-05	3.3E-03
9	0.09	0.04	0.04	0.33	0.01	0.38	0.01	0.09	0.03		0.09	9.5E-04	0.02
10	0.30	0.58	0.68	1.8E-04	0.10	1.5E-03	0.14	7.4E-05	0.57	0.09		2.0E-03	0.02
11	3.2E-04	1.9E-06	5.2E-05	1.3E-10	4.2E-05	3.3E-07	7.3E-04	1.9E-08	7.0E-05	9.5E-04	2.0E-03		0.27
12	0.01	3.7E-04	2.8E-03	1.0E-06	2.2E-03	1.5E-04	0.01	2.6E-05	3.3E-03	0.02	0.02	0.27	

Table 29: Comparison of the right hand sensor by sensor. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 30 summarizes the nonzero average pressure results for both, left, and right hands for the full delivery scenario, region by region. The left hand produces significantly higher pressures than the right hand and as do the proximal region, fifth metacarpal, and index finger. Only the ring finger on the right hand indicates a significantly higher pressure than those on the left. These data continue the trend where the left hand generally creates higher pressures than the right.

Sensor	Nonzero Average Pressure (MPa)	STDEV.S	Left Nonzero Average Pressure (MPa)	STDEV.S	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	0.0080	0.0092	0.0089	0.0103	0.0070	0.0077	0.02
Distal	0.0121	0.0112	0.0129	0.0131	0.0112	0.0087	0.22
Proximal	0.0051	0.0045	0.0061	0.0046	0.0041	0.0042	5.9E-04
Fifth Metacarpal	0.0015	0.0024	0.0025	0.0030	0.0003	0.0002	6.3E-04
Thumb	0.0057	0.0084	0.0073	0.0123	0.0046	0.0035	0.17
Index	0.0125	0.0129	0.0161	0.0156	0.0083	0.0068	3.0E-03
Middle	0.0085	0.0069	0.0088	0.0057	0.0081	0.0080	0.59
Ring	0.0085	0.0069	0.0071	0.0042	0.0101	0.0088	0.03
Little	0.0080	0.0092	0.0083	0.0091	0.0076	0.0094	0.73

Table 30: Both, left, and right comparison of full delivery region data. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 31 compares both hands region by region to determine significance. The index finger has significantly higher values than everything else except for the distal region. The distal region has significantly higher values than everything else except for the index finger. The middle and ring fingers have significantly the same values and have significantly higher values than the proximal region, the fifth metacarpal, and the thumb. The fifth metacarpal has significantly lower pressures than every other region. The proximal region has significantly lower pressures than the whole hand, the distal region, the index finger, the middle finger, the ring finger, and the little finger. The thumb has significantly lower pressures than the whole hand, the distal region, the index finger, the middle finger, the ring finger, and the little finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		8.7E-08	1.1E-05	1.1E-07	0.04	3.3E-05	0.60	0.56	0.98
Distal	8.7E-08		7.4E-17	6.9E-12	7.5E-06	0.75	2.8E-03	3.7E-03	1.4E-03
Proximal	1.1E-05	7.4E-17		8.4E-09	0.46	4.0E-13	3.3E-07	2.3E-07	2.0E-04
Fifth Metacarpal	1.1E-07	6.9E-12	8.4E-09		3.3E-04	1.6E-09	7.5E-12	4.6E-12	4.6E-07
Thumb	0.04	7.5E-06	0.46	3.3E-04		1.1E-04	0.02	0.02	0.09
Index	3.3E-05	0.75	4.0E-13	1.6E-09	1.1E-04		0.01	0.01	0.01
Middle	0.60	2.8E-03	3.3E-07	7.5E-12	0.02	0.01		0.95	0.67
Ring	0.56	3.7E-03	2.3E-07	4.6E-12	0.02	0.01	0.95		0.64
Little	0.98	1.4E-03	2.0E-04	4.6E-07	0.09	0.01	0.67	0.64	

Table 31: Comparison of both hands region by region. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 32 compares the left hand region by region to determine significance. The index finger has significantly higher pressures than everything else except for the distal region. The distal region has significantly higher pressures than the whole hand, the proximal region, the fifth metacarpal, the middle finger, the ring finger, and the little finger. The middle finger and the whole hand have significantly the same pressures and have significantly higher pressures than the proximal region, the fifth metacarpal, and the thumb. The fifth metacarpal has significantly lower pressures than everything else. The proximal region has significantly lower pressures than the whole hand, the distal region, the index finger, the middle finger, and the little finger. The thumb has significantly lower pressures than the distal region and the index finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		9.5E-04	0.01	6.2E-04	0.42	3.5E-05	0.98	0.22	0.69
Distal	9.5E-04		3.8E-07	2.0E-05	0.03	0.17	0.03	2.1E-03	0.02
Proximal	6.5E-03	3.8E-07		4.3E-05	0.41	4.0E-09	1.4E-03	0.19	0.04
Fifth Metacarpal	6.2E-04	2.0E-05	4.3E-05		0.04	7.7E-06	1.6E-07	5.9E-07	9.5E-04
Thumb	0.42	0.03	0.41	0.04		0.01	0.44	0.93	0.67
Index	3.5E-05	0.17	4.0E-09	7.7E-06	0.01		2.5E-03	1.3E-04	2.3E-03
Middle	0.98	0.03	1.4E-03	1.6E-07	0.44	2.5E-03		0.08	0.71
Ring	0.22	2.1E-03	0.19	5.9E-07	0.93	1.3E-04	0.08		0.40
Little	0.69	0.02	0.04	9.5E-04	0.67	2.3E-03	0.71	0.40	

Table 32: Comparison of the left hand region by region. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 33 compares the right hand region by region to determine significance. The distal region has significantly higher pressures than everything else except for the ring finger. The ring finger has significantly higher pressures than the whole hand, the proximal region, the fifth metacarpal, and the thumb. The index finger has significantly higher pressures than the proximal region, the fifth metacarpal, and the thumb. The fifth metacarpal has significantly lower pressures than everything else. The proximal region has significantly lower pressures than the whole hand, the distal region, the index finger, the middle finger, the ring finger, and the little finger. The thumb has significantly lower pressures than the whole hand, the distal region, the index finger, the middle finger, the ring finger, and the little finger.

T-Tests	Whole Hand	Distal	Proximal	Fifth Metacarpal	Thumb	Index	Middle	Ring	Little
Whole Hand		3.7E-06	2.0E-04	1.1E-05	0.04	0.29	0.36	0.01	0.62
Distal	3.7E-06		2.8E-13	1.8E-09	2.6E-06	0.05	0.03	0.48	0.02
Proximal	2.0E-04	2.8E-13		9.0E-06	0.51	6.0E-06	5.0E-05	3.4E-08	1.3E-03
Fifth Metacarpal	1.1E-05	1.8E-09	9.0E-06		3.9E-08	6.1E-08	3.6E-06	2.2E-07	1.4E-04
Thumb	0.04	2.6E-06	0.51	3.9E-08		1.6E-03	0.01	1.9E-04	0.04
Index	0.29	0.05	6.0E-06	6.1E-08	1.6E-03		0.88	0.29	0.70
Middle	0.36	0.03	5.0E-05	3.6E-06	0.01	0.88		0.24	0.80
Ring	0.01	0.48	3.4E-08	2.2E-07	1.9E-04	0.29	0.24		0.20
Little	0.62	0.02	1.3E-03	1.4E-04	0.04	0.70	0.80	0.20	

Table 33: Comparison of the right hand region by region. A light green t-test cell indicates that the compared values are significantly different.

Table 34 shows the full delivery data to examine values specific to residents and staff on a sensor by sensor basis for both hands, the left hand, and the right hand. The residents tend to exert higher pressures overall and with the left hand. The staff members exert higher pressures with the right hand. Beyond these, there are few other significant relationships. The residents produce significantly higher pressures measured on sensor 3, which is a distal sensor, overall and on the left hand. This result suggests that a fingertip-based technique was preferentially employed by the residents. The residents and staff generate significantly the same pressures at sensor 4 on the left hand, a proximal sensor. Sensor 7 on the right hand is associated with significantly higher pressure for the staff than the residents.

Sensor		Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Left Nonzero Average Pressure (Psi)	STDEV.S	T-Test	Right Nonzero Average Pressure (Psi)	STDEV.S	T-Test
Whole Hand	**Residents (5)**	0.0085	0.0100	0.17	0.0100	0.0117	0.06	0.0069	0.0073	0.75
	Staff (4)	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
1	**Residents (5)**	0.0066	0.0079	0.71	0.0103	0.0106	0.92	0.0037	0.0038	0.33
	Staff (4)	0.0080	0.0127		0.0111	0.0181		0.0050	0.0024	
2	**Residents (5)**	0.0036	0.0040	0.71	0.0035	0.0028	0.24	0.0036	0.0033	0.23
	Staff (4)	0.0030	0.0040		0.0019	0.0019		0.0056	0.0044	
3	**Residents (5)**	0.0229	0.0138	0.02	0.0337	0.0165	6.8E-04	0.0104	0.0066	0.07
	Staff (4)	0.0173	0.0075		0.0128	0.0097		0.0148	0.0046	
4	**Residents (5)**	0.0059	0.0045	0.38	0.0071	0.0066	0.98	0.0036	0.0025	0.16
	Staff (4)	0.0057	0.0045		0.0070	0.0053		0.0022	0.0018	
5	**Residents (5)**	0.0126	0.0097	0.17	0.0121	0.0071	0.09	0.0131	0.0099	0.68
	Staff (4)	0.0085	0.0064		0.0077	0.0057		0.0117	0.0067	
6	**Residents (5)**	0.0051	0.0054	0.86	0.0074	0.0036	0.91	0.0027	0.0037	0.47
	Staff (4)	0.0043	0.0039		0.0072	0.0044		0.0037	0.0025	
7	**Residents (5)**	0.0105	0.0138	0.12	0.0094	0.0039	0.73	0.0117	0.0083	0.05
	Staff (4)	0.0063	0.0085		0.0089	0.0050		0.0187	0.0085	
8	**Residents (5)**	0.0049	0.0044	0.58	0.0043	0.0030	0.23	0.0057	0.0049	0.12
	Staff (4)	0.0039	0.0023		0.0055	0.0020		0.0031	0.0019	
9	**Residents (5)**	0.0087	0.0109	0.50	0.0078	0.0125	0.44	0.0097	0.0076	0.91
	Staff (4)	0.0103	0.0130		0.0114	0.0113		0.0103	0.0155	
10	**Residents (5)**	0.0067	0.0058	0.60	0.0068	0.0052	0.72	0.0065	0.0076	0.30
	Staff (4)	0.0063	0.0047		0.0075	0.0047		0.0035	0.0041	
11	**Residents (5)**	0.0012	0.0017	0.47	0.0017	0.0014	0.25	0.0003	0.0002	0.08
	Staff (4)	0.0013	0.0029		0.0031	0.0039		0.0004	0.0002	
12	**Residents (5)**	0.0010	0.0019	0.49	0.0022	0.0024	0.78	0.0002	0.0001	0.35
	Staff (4)	0.0016	0.0035		0.0029	0.0043		0.0003	0.0002	

Table 34: Sensor by sensor comparison of residents and staff both hands, the left hand, and right hand. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 35 provides nonzero average pressure and significance test data for measurements made on the residents and staff for both hands, the left hand, and the right hand. There are few significant results. The residents tend to apply more pressure overall and with the left hand, but this response pattern is not significant. The residents apply significantly more pressure in the distal region on the left hand, suggesting a more fingertip-based technique. The staff members apply significantly more pressure with the right metacarpal, but that pressure is still very low, only 0.0004 MPa. The residents apply significantly more pressure with the index finger on the left hand and overall.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Residents (5)**	0.0085	0.0100	0.17	0.0100	0.0117	0.06	0.0069	0.0073	0.75
	Staff (4)	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
Distal	**Residents (5)**	0.0128	0.0122	0.29	0.0152	0.0147	0.04	0.0102	0.0081	0.22
	Staff (4)	0.0113	0.0100		0.0104	0.0106		0.0122	0.0094	
Proximal	**Residents (5)**	0.0054	0.0050	0.34	0.0063	0.0048	0.75	0.0045	0.0050	0.33
	Staff (4)	0.0048	0.0039		0.0060	0.0043		0.0037	0.0032	
Fifth Metacarpal	**Residents (5)**	0.0011	0.0014	0.30	0.0018	0.0016	0.25	0.0003	0.0001	0.03
	Staff (4)	0.0018	0.0031		0.0031	0.0039		0.0004	0.0002	
Thumb	**Residents (5)**	0.0051	0.0062	0.64	0.0079	0.0090	0.85	0.0036	0.0034	0.11
	Staff (4)	0.0061	0.0097		0.0070	0.0140		0.0053	0.0035	
Index	**Residents (5)**	0.0152	0.0158	0.03	0.0204	0.0183	0.02	0.0078	0.0063	0.66
	Staff (4)	0.0095	0.0078		0.0102	0.0084		0.0088	0.0073	
Middle	**Residents (5)**	0.0091	0.0078	0.31	0.0099	0.0061	0.14	0.0083	0.0092	0.86
	Staff (4)	0.0077	0.0058		0.0075	0.0050		0.0079	0.0065	
Ring	**Residents (5)**	0.0079	0.0060	0.36	0.0070	0.0043	0.89	0.0090	0.0075	0.37
	Staff (4)	0.0092	0.0078		0.0072	0.0041		0.0113	0.0101	
Little	**Residents (5)**	0.0077	0.0086	0.72	0.0073	0.0095	0.40	0.0081	0.0076	0.70
	Staff (4)	0.0083	0.0100		0.0095	0.0087		0.0070	0.0115	

Table 35: Region by region comparison of residents and staff both hands, the left hand, and right hand. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates a significant result.

Overall, the fingers tend to provide higher pressures than the thumb and palm, with the palm having very low pressures. The distal region is associated with higher pressures than the proximal region. The residents and staff have few significant relationships.

Part 3 - Comparisons

Part 3.1 - Qualitative Comparison of Film Results and Traction Only

The results from the Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] and the Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) cannot be compared quantitatively, because they are measuring different qualities: the pressures in an area versus the pressures at specific points. However, they can be compared qualitatively to determine if the glove sensors are generally producing the correct readings and if the glove sensors are correctly positioned.

The comparative results are presented in Table 36. Overall, from highest to lowest pressures, the ranking of regions according to data from the pressure film is middle finger, ring finger, index finger, little finger, whole hand, thumb, and palm. The glove sensors rank the regions as index finger, ring finger, middle finger, whole hand, little finger, thumb, and fifth metacarpal. These are not perfect matches, but overall, they are quite comparable. In both cases, the fingers tend to produce higher pressures, and the palm/fifth metacarpal and thumb tend to exert lower pressures. For the left hand, the interpreted pressure film data again provides the basis for ranking the regions as middle finger, ring finger, index finger, little finger, whole hand, thumb, and palm. According to measurements with the glove sensors the regions rank as index finger, middle finger, ring finger, whole hand, little finger, thumb, and fifth metacarpal. While not perfect matches, again, the fingers tend to exert higher pressures, and the palm/fifth metacarpal and thumb tend to exert lower pressures. For the right hand, the regions are ranked according to the pressure-film data as middle finger, ring finger, index finger, little finger, whole hand, thumb, and palm. The ranking by regions from data collected through the glove sensors are ring finger, middle finger, little ringer, index finger, whole hand, thumb, and fifth metacarpal. Once more, the matches are not exact, but the fingers tend to provide higher pressures, while the palm/fifth metacarpal and thumb tend to produce lower pressures.

Differences in the exact order of the regions with the different measurement approaches may come from differences in computing the pressure or from the lack of resolution of the point-based glove sensors as compared to the area-based film. In principle, adding more glove sensors should lead to results more similar to the film results.

Pressure Film Weighted Averages				Glove Nonzero Pressure Averages			
Region	Average Region Pressure (MPa)	Left Average Region Pressure (MPa)	Right Average Region Pressure (MPa)	Region	Nonzero Average Pressure (MPa)	Left Nonzero Average Pressure (MPa)	Right Nonzero Average Pressure (MPa)
Whole Hand	0.0048	0.0055	0.0041	*Whole Hand*	0.0072	0.0078	0.0067
Palm	0.0019	0.0025	0.0012	*Fifth Metacarpal*	0.0007	0.0010	0.0004
Thumb	0.0043	0.0052	0.0034	*Thumb*	0.0036	0.0041	0.0032
Index	0.0100	0.0121	0.0079	*Index*	0.0108	0.0152	0.0060
Middle	0.0175	0.0203	0.0147	*Middle*	0.0085	0.0084	0.0087
Ring	0.0124	0.0136	0.0112	*Ring*	0.0086	0.0067	0.0107
Little	0.0064	0.0064	0.0065	*Little*	0.0070	0.0067	0.0072

Table 36: Qualitative comparison of the Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] and the Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) results. The distribution of applied pressures is illustrated by coloring from red (highest) to green.

Part 3.2 - Quantitative Comparison of Traction Only and Excessive Force

The traction only and excessive force results are compared in this section. Assuming that infant injuries truly result from excessive force alone instead of other factors of improper practice, such as large deflections of the head and high torque on the spinal cord, it thus would be expected that the excessive force condition of this study, in which the obstetricians modeled improper practice, would lead to significantly higher pressures than the traction only condition, in which the physicians modeled correct practice. Table 37 compares the traction only and excessive force conditions with t-tests to determine if there are significant differences. The excessive force condition does produce slightly higher averages in general, but on the whole, this observation is not significant. For the average of both hands, the excessive force condition does lead to significantly higher pressure on sensors 6 and 9. For the left hand, the excessive force condition contributed significantly higher pressure on sensors 6 and 12, but sensor 4 has significantly the same pressures for both the conditions. For the right hand, the excessive force condition provides significantly higher pressures on sensor 6. Sensors 2 and 5 show significantly the same pressures for both hands.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0072	0.0097	0.08	0.0078	0.0107	0.19	0.0067	0.0085	0.26
	Excessive Force	0.0087	0.0100		0.0093	0.0096		0.0079	0.0104	
1	**Traction Only**	0.0045	0.0054	0.21	0.0061	0.0071	0.32	0.0030	0.0025	0.48
	Excessive Force	0.0069	0.0085		0.0096	0.0106		0.0039	0.0043	
2	**Traction Only**	0.0026	0.0049	0.56	0.0013	0.0008	0.09	0.0035	0.0062	0.99
	Excessive Force	0.0034	0.0031		0.0034	0.0042		0.0034	0.0019	
3	**Traction Only**	0.0160	0.0185	0.47	0.0228	0.0231	0.40	0.0085	0.0052	0.82
	Excessive Force	0.0127	0.0113		0.0161	0.0141		0.0089	0.0057	
4	**Traction Only**	0.0051	0.0065	0.75	0.0066	0.0083	0.96	0.0034	0.0033	0.50
	Excessive Force	0.0056	0.0043		0.0064	0.0046		0.0044	0.0038	
5	**Traction Only**	0.0108	0.0090	0.36	0.0091	0.0071	0.17	0.0127	0.0105	0.97
	Excessive Force	0.0130	0.0098		0.0133	0.0106		0.0128	0.0095	
6	**Traction Only**	0.0057	0.0036	2.2E-03	0.0073	0.0037	0.04	0.0045	0.0030	0.03
	Excessive Force	0.0104	0.0078		0.0125	0.0090		0.0081	0.0061	
7	**Traction Only**	0.0109	0.0105	0.11	0.0081	0.0052	0.53	0.0139	0.0136	0.11
	Excessive Force	0.0158	0.0140		0.0093	0.0053		0.0230	0.0172	
8	**Traction Only**	0.0060	0.0064	0.85	0.0052	0.0049	0.22	0.0070	0.0079	0.19
	Excessive Force	0.0057	0.0063		0.0078	0.0074		0.0033	0.0039	
9	**Traction Only**	0.0070	0.0070	0.05	0.0064	0.0059	0.16	0.0077	0.0080	0.16
	Excessive Force	0.0123	0.0150		0.0111	0.0146		0.0139	0.0165	
10	**Traction Only**	0.0069	0.0083	0.89	0.0070	0.0056	0.38	0.0067	0.0105	0.44
	Excessive Force	0.0066	0.0066		0.0093	0.0075		0.0035	0.0038	
11	**Traction Only**	0.0009	0.0011	0.09	0.0012	0.0012	0.06	0.0004	0.0004	0.64
	Excessive Force	0.0020	0.0034		0.0031	0.0042		0.0005	0.0007	
12	**Traction Only**	0.0005	0.0004	0.06	0.0006	0.0003	0.04	0.0004	0.0004	0.50
	Excessive Force	0.0012	0.0016		0.0026	0.0028		0.0006	0.0006	

Table 37: Traction only versus excessive force conditions comparison, sensor by sensor. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 38 compares results for the traction only and excessive force conditions on a region by region basis to determine significant relationships. With the excessive force condition, pressures are significantly higher overall and with the left hand for the fifth metacarpal and the middle finger. The right hand shows no significant relationships.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0072	0.0097	0.08	0.0078	0.0107	0.19	0.0067	0.0085	0.26
	Excessive Force	0.0087	0.0100		0.0093	0.0096		0.0079	0.0104	
Distal	**Traction Only**	0.0102	0.0118	0.15	0.0108	0.0135	0.62	0.0095	0.0097	0.09
	Excessive Force	0.0123	0.0121		0.0119	0.0114		0.0127	0.0129	
Proximal	**Traction Only**	0.0054	0.0063	0.26	0.0058	0.0058	0.06	0.0050	0.0067	0.65
	Excessive Force	0.0063	0.0062		0.0080	0.0071		0.0045	0.0043	
Fifth Metacarpal	**Traction Only**	0.0007	0.0009	0.02	0.0010	0.0011	0.01	0.0004	0.0004	0.41
	Excessive Force	0.0018	0.0029		0.0030	0.0038		0.0006	0.0006	
Thumb	**Traction Only**	0.0036	0.0052	0.17	0.0041	0.0058	0.20	0.0032	0.0047	0.73
	Excessive Force	0.0053	0.0067		0.0069	0.0088		0.0037	0.0032	
Index	**Traction Only**	0.0108	0.0151	0.66	0.0152	0.0194	0.45	0.0060	0.0050	0.46
	Excessive Force	0.0096	0.0095		0.0115	0.0116		0.0071	0.0054	
Middle	**Traction Only**	0.0085	0.0075	0.03	0.0084	0.0060	0.02	0.0087	0.0088	0.37
	Excessive Force	0.0119	0.0090		0.0129	0.0096		0.0109	0.0084	
Ring	**Traction Only**	0.0086	0.0091	0.24	0.0067	0.0052	0.19	0.0107	0.0117	0.49
	Excessive Force	0.0107	0.0119		0.0086	0.0063		0.0132	0.0158	
Little	**Traction Only**	0.0070	0.0076	0.13	0.0067	0.0058	0.09	0.0072	0.0092	0.56
	Excessive Force	0.0097	0.0121		0.0103	0.0117		0.0090	0.0131	

Table 38: Traction only versus excessive force conditions comparison, region by region. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 39 compares the traction only versus excessive force conditions sensor by sensor for the residents only. The analysis tests whether the residents change their behavior significantly between the two conditions. The results for the residents show few significant differences between the traction only and excessive force conditions. On sensor 6 overall and on the right, the excessive force condition results in significantly higher pressures. Comparing data from sensor 8 on the left hand, the two conditions produce significantly the same pressures.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0081	0.0109	0.84	0.0088	0.0121	0.53	0.0073	0.0094	0.68
	Excessive Force	0.0078	0.0093		0.0077	0.0080		0.0080	0.0107	
1	**Traction Only**	0.0054	0.0068	0.75	0.0081	0.0088	0.69	0.0030	0.0030	0.76
	Excessive Force	0.0046	0.0037		0.0064	0.0038		0.0024	0.0025	
2	**Traction Only**	0.0019	0.0021	0.10	0.0011	0.0006	0.12	0.0024	0.0025	0.64
	Excessive Force	0.0038	0.0035		0.0044	0.0047		0.0030	0.0007	
3	**Traction Only**	0.0203	0.0209	0.42	0.0292	0.0246	0.49	0.0094	0.0060	0.35
	Excessive Force	0.0148	0.0140		0.0217	0.0158		0.0065	0.0048	
4	**Traction Only**	0.0057	0.0075	0.60	0.0075	0.0094	0.89	0.0036	0.0038	0.42
	Excessive Force	0.0070	0.0044		0.0080	0.0045		0.0054	0.0045	
5	**Traction Only**	0.0118	0.0097	0.72	0.0098	0.0066	0.80	0.0140	0.0121	0.55
	Excessive Force	0.0107	0.0073		0.0106	0.0059		0.0107	0.0090	
6	**Traction Only**	0.0065	0.0036	0.02	0.0080	0.0031	0.28	0.0051	0.0035	0.04
	Excessive Force	0.0107	0.0068		0.0107	0.0074		0.0107	0.0071	
7	**Traction Only**	0.0131	0.0123	0.84	0.0094	0.0052	0.36	0.0172	0.0164	0.60
	Excessive Force	0.0140	0.0159		0.0073	0.0029		0.0221	0.0218	
8	**Traction Only**	0.0065	0.0069	0.53	0.0056	0.0046	0.97	0.0076	0.0091	0.46
	Excessive Force	0.0051	0.0045		0.0057	0.0044		0.0043	0.0050	
9	**Traction Only**	0.0057	0.0046	0.38	0.0049	0.0047	0.44	0.0067	0.0045	0.09
	Excessive Force	0.0080	0.0119		0.0032	0.0034		0.0152	0.0170	
10	**Traction Only**	0.0070	0.0086	0.38	0.0055	0.0050	0.61	0.0089	0.0116	0.46
	Excessive Force	0.0042	0.0033		0.0041	0.0021		0.0043	0.0046	
11	**Traction Only**	0.0008	0.0004	0.06	0.0008	1.0000	0.09	0.0006	0.0005	0.43
	Excessive Force	0.0013	0.0009		0.0014	0.0010		0.0010	0.0012	
12	**Traction Only**	0.0006	0.0004	0.47	0.0007	0.0003	#DIV/0!	0.0005	0.0004	0.42
	Excessive Force	0.0008	0.0005		0.0007	#DIV/0!		0.0008	0.0007	

Table 39: Traction only versus excessive force conditions comparison, sensor by sensor, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same. #DIV/0! indicates that there were not enough values to calculate that term.

Table 40 compares the traction only versus excessive force conditions region by region for the residents only to determine whether they change their behavior significantly between the two conditions. The results point to significantly the same pressures when comparing the left proximal regions, left thumbs, and overall average little fingers. With the excessive force condition, significantly higher pressures are generated on the fifth metacarpal on average overall.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0081	0.0109	0.84	0.0088	0.0121	0.53	0.0073	0.0094	0.68
	Excessive Force	0.0078	0.0093		0.0077	0.0080		0.0080	0.0107	
Distal	**Traction Only**	0.0116	0.0134	0.65	0.0128	0.0153	0.35	0.0105	0.0111	0.69
	Excessive Force	0.0107	0.0117		0.0100	0.0100		0.0116	0.0138	
Proximal	**Traction Only**	0.0058	0.0065	0.74	0.0061	0.0061	0.68	0.0055	0.0070	1.00
	Excessive Force	0.0062	0.0051		0.0067	0.0052		0.0055	0.0051	
Fifth Metacarpal	**Traction Only**	0.0007	0.0004	0.03	0.0008	0.0003	0.08	0.0005	0.0004	0.21
	Excessive Force	0.0011	0.0008		0.0013	0.0009		0.0009	0.0008	
Thumb	**Traction Only**	0.0040	0.0056	0.86	0.0056	0.0078	0.94	0.0027	0.0027	0.98
	Excessive Force	0.0042	0.0035		0.0054	0.0042		0.0027	0.0017	
Index	**Traction Only**	0.0128	0.0172	0.66	0.0183	0.0214	0.60	0.0064	0.0057	0.85
	Excessive Force	0.0111	0.0111		0.0149	0.0131		0.0060	0.0044	
Middle	**Traction Only**	0.0094	0.0080	0.51	0.0091	0.0054	0.43	0.0097	0.0100	0.77
	Excessive Force	0.0107	0.0069		0.0107	0.0063		0.0107	0.0079	
Ring	**Traction Only**	0.0099	0.0106	0.89	0.0076	0.0052	0.52	0.0128	0.0141	0.93
	Excessive Force	0.0095	0.0123		0.0065	0.0037		0.0132	0.0176	
Little	**Traction Only**	0.0063	0.0067	0.99	0.0051	0.0047	0.33	0.0076	0.0083	0.59
	Excessive Force	0.0063	0.0091		0.0036	0.0028		0.0098	0.0129	

Table 40: Traction only versus excessive force conditions comparison, region by region, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 41 compares the traction only versus excessive force conditions sensor by sensor for the staff only to determine whether the staff members change their behavior significant with the two conditions. Overall and for the left hand, the staff members use significantly higher pressure with the excessive force condition. The staff members seem more enthusiastic about the excessive force trial and more willing to use it as a teachable moment about bad practice. The excessive force condition also yields significantly higher pressures for the overall average of sensors 1, 6, 9, and 11, and the left sensor 9, and the right sensor 7.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0061	0.0077	1.0E-03	0.0063	0.0082	1.4E-03	0.0059	0.0072	0.17
	Excessive Force	0.0098	0.0108		0.0117	0.0112		0.0079	0.0103	
1	**Traction Only**	0.0033	0.0018	0.01	0.0035	0.0021	0.09	0.0031	0.0016	0.27
	Excessive Force	0.0135	0.0157		0.0135	0.0157		0.0054	0.0055	
2	**Traction Only**	0.0032	0.0063	0.62	0.0015	0.0009	0.37	0.0044	0.0082	0.90
	Excessive Force	0.0009	0.0001		0.0009	0.0001		0.0038	0.0028	
3	**Traction Only**	0.0106	0.0133	0.69	0.0138	0.0182	0.54	0.0074	0.0041	0.10
	Excessive Force	0.0078	0.0055		0.0078	0.0055		0.0120	0.0058	
4	**Traction Only**	0.0040	0.0044	0.80	0.0050	0.0058	0.64	0.0029	0.0022	0.74
	Excessive Force	0.0032	0.0033		0.0032	0.0033		0.0024	0.0006	
5	**Traction Only**	0.0095	0.0080	0.13	0.0080	0.0080	0.14	0.0109	0.0080	0.32
	Excessive Force	0.0173	0.0156		0.0173	0.0156		0.0160	0.0105	
6	**Traction Only**	0.0047	0.0035	3.2E-03	0.0062	0.0046	0.09	0.0036	0.0021	0.44
	Excessive Force	0.0154	0.0124		0.0154	0.0124		0.0047	0.0025	
7	**Traction Only**	0.0080	0.0065	0.23	0.0062	0.0048	0.07	0.0097	0.0077	0.01
	Excessive Force	0.0124	0.0071		0.0124	0.0071		0.0242	0.0126	
8	**Traction Only**	0.0054	0.0059	0.13	0.0047	0.0055	0.13	0.0063	0.0064	0.22
	Excessive Force	0.0111	0.0104		0.0111	0.0104		0.0020	0.0014	
9	**Traction Only**	0.0087	0.0090	0.02	0.0084	0.0070	0.03	0.0089	0.0109	0.64
	Excessive Force	0.0229	0.0175		0.0229	0.0175		0.0125	0.0184	
10	**Traction Only**	0.0067	0.0081	0.09	0.0091	0.0060	0.19	0.0045	0.0094	0.71
	Excessive Force	0.0144	0.0074		0.0144	0.0074		0.0023	0.0029	
11	**Traction Only**	0.0011	0.0015	0.02	0.0016	0.0018	0.09	0.0003	0.0002	0.88
	Excessive Force	0.0051	0.0059		0.0051	0.0059		0.0003	0.0002	
12	**Traction Only**	0.0003	0.0002	#DIV/0!	0.0005	0.0001	#DIV/0!	0.0001	0.0001	0.28
	Excessive Force	0.0046	#DIV/0!		0.0046	#DIV/0!		0.0003	0.0002	

Table 41: Traction only versus excessive force conditions comparison, sensor by sensor, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. #DIV/0! indicates that there were not enough values to calculate that term.

This analysis compares the traction only versus excessive force conditions region by region for the staff only. The question is whether the staff members display any significant changes in their behavior between the two conditions. Table 42 indicates that staff members provide significantly higher pressure values for the excessive force condition for the whole hand overall, the distal region overall, the middle finger overall, the ring finger overall, the little finger overall, the whole hand on the left hand, the left hand distal region, the left hand proximal region, the left hand fifth metacarpal, the left hand middle finger, the left hand ring finger, the hand little finger, and the right hand distal region. The pressure increases on the distal region and on the middle, ring, and little fingers may indicate that it is expedient to apply considerable pressure in a hurry with the fingertips.

Region		**Nonzero Average Pressure (MPa)**	**STDEV.S**	**T-Test**	**Left Nonzero Average Pressure (MPa)**	**STDEV.S**	**T-Test**	**Right Nonzero Average Pressure (MPa)**	**STDEV.S**	**T-Test**
Whole Hand	**Traction Only**	0.0061	0.0077	1.0E-03	0.0063	0.0082	1.4E-03	0.0059	0.0072	0.17
	Excessive Force	0.0098	0.0108		0.0117	0.0112		0.0079	0.0103	
Distal	**Traction Only**	0.0083	0.0090	1.2E-03	0.0083	0.0102	0.03	0.0084	0.0076	0.02
	Excessive Force	0.0144	0.0123		0.0148	0.0129		0.0140	0.0121	
Proximal	**Traction Only**	0.0049	0.0059	0.20	0.0054	0.0054	0.02	0.0044	0.0064	0.44
	Excessive Force	0.0065	0.0075		0.0100	0.0093		0.0031	0.0022	
Fifth Metacarpal	**Traction Only**	0.0009	0.0013	0.09	0.0013	0.0016	0.03	0.0002	0.0002	0.64
	Excessive Force	0.0024	0.0041		0.0050	0.0051		0.0003	0.0002	
Thumb	**Traction Only**	0.0032	0.0048	0.10	0.0025	0.0019	0.06	0.0038	0.0063	0.75
	Excessive Force	0.0066	0.0094		0.0093	0.0138		0.0046	0.0041	
Index	**Traction Only**	0.0077	0.0109	0.87	0.0100	0.0147	0.48	0.0055	0.0040	0.14
	Excessive Force	0.0072	0.0058		0.0059	0.0050		0.0088	0.0067	
Middle	**Traction Only**	0.0073	0.0068	0.01	0.0073	0.0067	0.02	0.0074	0.0069	0.26
	Excessive Force	0.0138	0.0115		0.0164	0.0132		0.0112	0.0097	
Ring	**Traction Only**	0.0067	0.0063	0.02	0.0055	0.0051	0.02	0.0081	0.0072	0.22
	Excessive Force	0.0124	0.0114		0.0117	0.0083		0.0131	0.0145	
Little	**Traction Only**	0.0077	0.0085	0.05	0.0087	0.0064	0.01	0.0068	0.0102	0.78
	Excessive Force	0.0138	0.0143		0.0186	0.0133		0.0082	0.0142	

Table 42: Traction only versus excessive force conditions comparison, region by region, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. #DIV/0! indicates that there are not enough values to calculate that term.

Part 3.3 - Quantitative Comparison of Traction Only and Full Delivery

Pressures exerted upon the infant during the downward traction phase are often thought to be large. The full delivery condition contains the downward traction phase but also other actions that are thought to be lower pressure. If that is the case, one would expect the full delivery condition to involve lower pressures and lower overall average pressure than the traction only phase. Table 43 summarizes the average nonzero pressures sensor by sensor for the traction only and full delivery conditions and compares them for significance using t-tests. The full delivery condition actually has slightly higher pressures on average but differences with traction only are rarely significant. The full delivery condition produces significantly higher pressure on sensor 3 on the right hand. The two conditions yield significantly the same pressure on the left sensor 6 and the left sensor 10.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0072	0.0097	0.20	0.0078	0.0107	0.21	0.0067	0.0085	0.66
	Full Delivery	0.0080	0.0092		0.0089	0.0103		0.0070	0.0077	
1	**Traction Only**	0.0045	0.0054	0.15	0.0061	0.0071	0.24	0.0030	0.0025	0.10
	Full Delivery	0.0074	0.0109		0.0108	0.0153		0.0044	0.0031	
2	**Traction Only**	0.0026	0.0049	0.23	0.0013	0.0008	0.11	0.0035	0.0062	0.45
	Full Delivery	0.0038	0.0036		0.0024	0.0022		0.0046	0.0040	
3	**Traction Only**	0.0160	0.0185	0.41	0.0228	0.0231	0.78	0.0085	0.0052	0.01
	Full Delivery	0.0187	0.0143		0.0244	0.0172		0.0125	0.0060	
4	**Traction Only**	0.0051	0.0065	0.89	0.0066	0.0083	0.82	0.0034	0.0033	0.49
	Full Delivery	0.0052	0.0052		0.0071	0.0060		0.0028	0.0022	
5	**Traction Only**	0.0108	0.0090	0.75	0.0091	0.0071	0.56	0.0127	0.0105	0.94
	Full Delivery	0.0113	0.0077		0.0102	0.0068		0.0125	0.0085	
6	**Traction Only**	0.0057	0.0036	0.53	0.0073	0.0037	0.99	0.0045	0.0030	0.14
	Full Delivery	0.0052	0.0041		0.0073	0.0039		0.0031	0.0032	
7	**Traction Only**	0.0109	0.0105	0.52	0.0081	0.0052	0.40	0.0139	0.0136	0.71
	Full Delivery	0.0120	0.0075		0.0092	0.0043		0.0151	0.0090	
8	**Traction Only**	0.0060	0.0064	0.19	0.0052	0.0049	0.77	0.0070	0.0079	0.17
	Full Delivery	0.0047	0.0032		0.0049	0.0026		0.0044	0.0038	
9	**Traction Only**	0.0070	0.0070	0.16	0.0064	0.0059	0.24	0.0077	0.0080	0.42
	Full Delivery	0.0097	0.0115		0.0094	0.0119		0.0100	0.0114	
10	**Traction Only**	0.0069	0.0083	0.68	0.0070	0.0056	0.95	0.0067	0.0105	0.59
	Full Delivery	0.0063	0.0056		0.0071	0.0049		0.0053	0.0063	
11	**Traction Only**	0.0009	0.0011	0.21	0.0012	0.0012	0.08	0.0004	0.0004	0.59
	Full Delivery	0.0015	0.0023		0.0024	0.0028		0.0004	0.0002	
12	**Traction Only**	0.0005	0.0004	0.10	0.0006	0.0003	0.13	0.0004	0.0004	0.34
	Full Delivery	0.0015	0.0028		0.0027	0.0036		0.0003	0.0001	

Table 43: Traction only versus full delivery conditions comparison, sensor by sensor. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 44 summarizes the average nonzero pressures region by region for the traction only and full delivery conditions and tests for the significance of differences with t-tests. Again, the full delivery condition provides slightly higher pressure on average; but rarely are relationships significant. The full delivery condition is associated with significantly higher pressures on the fifth metacarpal overall and on the left hand. The two conditions provide significantly the same pressures on the ring finger overall.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	Traction Only	0.0072	0.0097	0.20	0.0078	0.0107	0.21	0.0067	0.0085	0.66
	Full Delivery	0.0080	0.0092		0.0089	0.0103		0.0070	0.0077	
Distal	Traction Only	0.0102	0.0118	0.07	0.0108	0.0135	0.21	0.0095	0.0097	0.17
	Full Delivery	0.0121	0.0112		0.0129	0.0131		0.0112	0.0087	
Proximal	Traction Only	0.0054	0.0063	0.58	0.0058	0.0058	0.66	0.0050	0.0067	0.23
	Full Delivery	0.0051	0.0045		0.0061	0.0046		0.0041	0.0042	
Fifth Metacarpal	Traction Only	0.0007	0.0009	0.04	0.0010	0.0011	0.02	0.0004	0.0004	0.31
	Full Delivery	0.0015	0.0024		0.0025	0.0030		0.0003	0.0002	
Thumb	Traction Only	0.0036	0.0052	0.07	0.0041	0.0058	0.19	0.0032	0.0047	0.14
	Full Delivery	0.0057	0.0084		0.0073	0.0123		0.0046	0.0035	
Index	Traction Only	0.0108	0.0151	0.39	0.0152	0.0194	0.79	0.0060	0.0050	0.06
	Full Delivery	0.0125	0.0129		0.0161	0.0156		0.0083	0.0068	
Middle	Traction Only	0.0085	0.0075	0.93	0.0084	0.0060	0.68	0.0087	0.0088	0.70
	Full Delivery	0.0085	0.0069		0.0088	0.0057		0.0081	0.0080	
Ring	Traction Only	0.0086	0.0091	0.97	0.0067	0.0052	0.63	0.0107	0.0117	0.77
	Full Delivery	0.0085	0.0069		0.0071	0.0042		0.0101	0.0088	
Little	Traction Only	0.0070	0.0076	0.39	0.0067	0.0058	0.29	0.0072	0.0092	0.84
	Full Delivery	0.0080	0.0092		0.0083	0.0091		0.0076	0.0094	

Table 44: Traction only versus full delivery conditions comparison, region by region. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

The next four sets of comparisons look at differences in behavior of residents for the two conditions. Table 45 summarizes the average nonzero pressures sensor by sensor for the traction only and full delivery conditions and compares them using t-tests for the residents only. The full delivery condition tends to produce higher pressure averages, but there are not many significant relationships. The two conditions produce significantly the same pressures on sensor 4 on the right and sensor 7 on the left. The full delivery condition has significantly higher pressures on sensor 11 on the left.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0081	0.0109	0.62	0.0088	0.0121	0.37	0.0073	0.0094	0.66
	Full Delivery	0.0085	0.0100		0.0100	0.0117		0.0069	0.0073	
1	**Traction Only**	0.0054	0.0068	0.62	0.0081	0.0088	0.63	0.0030	0.0030	0.63
	Full Delivery	0.0066	0.0080		0.0103	0.0106		0.0037	0.0038	
2	**Traction Only**	0.0019	0.0021	0.08	0.0011	0.0006	0.07	0.0024	0.0025	0.36
	Full Delivery	0.0036	0.0030		0.0035	0.0028		0.0036	0.0033	
3	**Traction Only**	0.0203	0.0209	0.60	0.0292	0.0246	0.56	0.0094	0.0060	0.66
	Full Delivery	0.0229	0.0173		0.0337	0.0165		0.0104	0.0066	
4	**Traction Only**	0.0057	0.0075	0.91	0.0075	0.0094	0.90	0.0036	0.0038	0.98
	Full Delivery	0.0059	0.0057		0.0071	0.0066		0.0036	0.0025	
5	**Traction Only**	0.0118	0.0097	0.71	0.0098	0.0066	0.33	0.0140	0.0121	0.83
	Full Delivery	0.0126	0.0085		0.0121	0.0071		0.0131	0.0099	
6	**Traction Only**	0.0065	0.0036	0.22	0.0080	0.0031	0.64	0.0051	0.0035	0.09
	Full Delivery	0.0051	0.0043		0.0074	0.0036		0.0027	0.0037	
7	**Traction Only**	0.0131	0.0123	0.32	0.0094	0.0052	0.99	0.0172	0.0164	0.28
	Full Delivery	0.0105	0.0063		0.0094	0.0039		0.0117	0.0083	
8	**Traction Only**	0.0065	0.0069	0.33	0.0056	0.0046	0.38	0.0076	0.0091	0.54
	Full Delivery	0.0049	0.0039		0.0043	0.0030		0.0057	0.0049	
9	**Traction Only**	0.0057	0.0046	0.16	0.0049	0.0047	0.39	0.0067	0.0045	0.21
	Full Delivery	0.0087	0.0103		0.0078	0.0125		0.0097	0.0076	
10	**Traction Only**	0.0070	0.0086	0.86	0.0055	0.0050	0.50	0.0089	0.0116	0.55
	Full Delivery	0.0067	0.0063		0.0068	0.0052		0.0065	0.0076	
11	**Traction Only**	0.0008	0.0004	0.21	0.0008	1.0000	0.05	0.0006	0.0005	0.16
	Full Delivery	0.0012	0.0013		0.0017	0.0014		0.0003	0.0002	
12	**Traction Only**	0.0006	0.0004	0.39	0.0007	0.0003	0.21	0.0005	0.0004	0.18
	Full Delivery	0.0010	0.0016		0.0022	0.0024		0.0002	0.0001	

Table 45: Traction only versus full delivery conditions comparison, sensor by sensor, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 46 summarizes the average nonzero pressures for the residents region by region for the traction only and full delivery conditions. The t-tests indicate whether the residents produce any significant pressure changes between the two conditions. The full delivery condition tends to produce higher pressure averages, but there are not many significant relationships. The traction only condition creates significantly higher pressures than the full delivery condition with the right fifth metacarpal, but the value is still low (0.0005 MPa). The traction only condition also is associated with significantly higher pressures than the full delivery condition on the left ring finger, but the value there (0.0076 MPa) is not exceptionally high.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	Traction Only	0.0081	0.0109	0.62	0.0088	0.0121	0.37	0.0073	0.0094	0.66
	Full Delivery	0.0085	0.0100		0.0100	0.0117		0.0069	0.0073	
Distal	Traction Only	0.0116	0.0134	0.45	0.0128	0.0153	0.34	0.0105	0.0111	0.89
	Full Delivery	0.0128	0.0122		0.0152	0.0147		0.0102	0.0081	
Proximal	Traction Only	0.0058	0.0065	0.57	0.0061	0.0061	0.90	0.0055	0.0070	0.36
	Full Delivery	0.0054	0.0050		0.0063	0.0048		0.0045	0.0050	
Fifth Metacarpal	Traction Only	0.0007	0.0004	0.09	0.0008	0.0003	0.17	0.0005	0.0004	0.04
	Full Delivery	0.0011	0.0014		0.0013	0.0015		0.0003	0.0001	
Thumb	Traction Only	0.0040	0.0056	0.42	0.0056	0.0078	0.70	0.0027	0.0027	0.34
	Full Delivery	0.0051	0.0062		0.0072	0.0135		0.0036	0.0034	
Index	Traction Only	0.0128	0.0172	0.45	0.0183	0.0214	0.63	0.0064	0.0057	0.41
	Full Delivery	0.0152	0.0158		0.0207	0.0168		0.0078	0.0063	
Middle	Traction Only	0.0094	0.0080	0.83	0.0091	0.0054	0.67	0.0097	0.0100	0.57
	Full Delivery	0.0091	0.0078		0.0098	0.0072		0.0083	0.0092	
Ring	Traction Only	0.0099	0.0106	0.23	0.0076	0.0052	0.04	0.0128	0.0141	0.24
	Full Delivery	0.0079	0.0060		0.0052	0.0031		0.0090	0.0075	
Little	Traction Only	0.0063	0.0067	0.35	0.0051	0.0047	0.75	0.0076	0.0083	0.84
	Full Delivery	0.0077	0.0086		0.0047	0.0052		0.0081	0.0076	

Table 46: Traction only versus fully delivery conditions comparison, region by region, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

The next two tables present comparative analyses for the staff for the traction only and full delivery conditions. Table 47 summarizes the average nonzero pressures sensor by sensor and tests for significant differences with t-tests. Again, there are few significant results. The full delivery condition did result in significantly higher pressures on the right sensor 3, overall average sensor 7, right sensor 7, and right sensor 12.

<u>Sensor</u>		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0061	0.0077	0.08	0.0063	0.0082	0.22	0.0059	0.0072	0.20
	Full Delivery	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
1	**Traction Only**	0.0033	0.0018	0.15	0.0035	0.0021	0.26	0.0031	0.0016	0.06
	Full Delivery	0.0079	0.0127		0.0111	0.0181		0.0050	0.0024	
2	**Traction Only**	0.0032	0.0063	0.63	0.0015	0.0009	0.64	0.0044	0.0082	0.67
	Full Delivery	0.0040	0.0040		0.0019	0.0019		0.0056	0.0044	
3	**Traction Only**	0.0106	0.0133	0.31	0.0138	0.0182	0.87	0.0074	0.0041	4.0E-04
	Full Delivery	0.0138	0.0075		0.0128	0.0097		0.0148	0.0046	
4	**Traction Only**	0.0040	0.0044	0.71	0.0050	0.0058	0.43	0.0029	0.0022	0.41
	Full Delivery	0.0045	0.0045		0.0070	0.0053		0.0022	0.0018	
5	**Traction Only**	0.0095	0.0080	0.91	0.0080	0.0080	0.91	0.0109	0.0080	0.79
	Full Delivery	0.0097	0.0064		0.0077	0.0057		0.0117	0.0067	
6	**Traction Only**	0.0047	0.0035	0.55	0.0062	0.0046	0.61	0.0036	0.0021	0.93
	Full Delivery	0.0054	0.0039		0.0072	0.0044		0.0037	0.0025	
7	**Traction Only**	0.0080	0.0065	0.01	0.0062	0.0048	0.20	0.0097	0.0077	0.01
	Full Delivery	0.0138	0.0085		0.0089	0.0050		0.0187	0.0085	
8	**Traction Only**	0.0054	0.0059	0.44	0.0047	0.0055	0.63	0.0063	0.0064	0.14
	Full Delivery	0.0044	0.0023		0.0055	0.0020		0.0031	0.0019	
9	**Traction Only**	0.0087	0.0090	0.50	0.0084	0.0070	0.44	0.0089	0.0109	0.81
	Full Delivery	0.0109	0.0130		0.0114	0.0113		0.0103	0.0155	
10	**Traction Only**	0.0067	0.0081	0.66	0.0091	0.0060	0.50	0.0045	0.0094	0.78
	Full Delivery	0.0058	0.0047		0.0075	0.0047		0.0035	0.0041	
11	**Traction Only**	0.0011	0.0015	0.44	0.0016	0.0018	0.25	0.0003	0.0002	0.28
	Full Delivery	0.0017	0.0029		0.0031	0.0039		0.0004	0.0002	
12	**Traction Only**	0.0003	0.0002	0.25	0.0005	0.0001	0.38	0.0001	0.0001	0.04
	Full Delivery	0.0019	0.0035		0.0029	0.0043		0.0003	0.0002	

Table 47: Traction only versus full delivery conditions comparison, sensor by sensor, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

The average nonzero pressures are evaluated in Table 48 region by region for the traction only and full delivery conditions. The t-tests for the staff determine if they produce any significant behavioral changes between the two conditions. For the full delivery condition, there are significantly higher pressures recorded in the overall average distal region, the right distal region, and the right fifth metacarpal. Both conditions provide significantly the same values for the overall average proximal region, the left index finger, and the right little finger.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Traction Only**	0.0061	0.0077	0.08	0.0063	0.0082	0.22	0.0059	0.0072	0.20
	Full Delivery	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
Distal	**Traction Only**	0.0083	0.0090	0.02	0.0083	0.0102	0.29	0.0084	0.0076	0.02
	Full Delivery	0.0113	0.0100		0.0104	0.0106		0.0122	0.0094	
Proximal	**Traction Only**	0.0049	0.0059	0.95	0.0054	0.0054	0.56	0.0044	0.0064	0.50
	Full Delivery	0.0048	0.0039		0.0060	0.0043		0.0037	0.0032	
Fifth Metacarpal	**Traction Only**	0.0009	0.0013	0.18	0.0013	0.0016	0.14	0.0002	0.0002	0.04
	Full Delivery	0.0018	0.0031		0.0031	0.0039		0.0004	0.0002	
Thumb	**Traction Only**	0.0032	0.0048	0.12	0.0025	0.0019	0.22	0.0038	0.0063	0.33
	Full Delivery	0.0061	0.0097		0.0070	0.0140		0.0053	0.0035	
Index	**Traction Only**	0.0077	0.0109	0.40	0.0100	0.0147	0.96	0.0055	0.0040	0.08
	Full Delivery	0.0095	0.0078		0.0102	0.0084		0.0088	0.0073	
Middle	**Traction Only**	0.0073	0.0068	0.80	0.0073	0.0067	0.90	0.0074	0.0069	0.82
	Full Delivery	0.0077	0.0058		0.0075	0.0050		0.0079	0.0065	
Ring	**Traction Only**	0.0067	0.0063	0.10	0.0055	0.0051	0.20	0.0081	0.0072	0.24
	Full Delivery	0.0092	0.0078		0.0072	0.0041		0.0113	0.0101	
Little	**Traction Only**	0.0077	0.0085	0.76	0.0087	0.0064	0.74	0.0068	0.0102	0.95
	Full Delivery	0.0083	0.0100		0.0095	0.0087		0.0070	0.0115	

Table 48: Traction only versus full delivery conditions comparison, region by region, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Part 3.4- Quantitative Comparison of Excessive Force and Full Delivery

If damage is caused solely by the application of too much pressure, then the excessive force condition, which model poor clinical practice, should have higher pressures than the full delivery condition. Table 49 summarizes the average nonzero pressures sensor by sensor for the excessive force and full delivery conditions and compares them with t-tests. The excessive force condition usually has slightly higher averages than the full delivery condition, but this observation is rarely significant. The full delivery condition has significantly higher pressures for sensor 6 overall, on the left, and on the right. For the left sensor 12, both conditions have significantly the same pressures.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Excessive Force**	0.0087	0.0100	0.37	0.0093	0.0096	0.71	0.0079	0.0104	0.37
	Full Delivery	0.0080	0.0092		0.0089	0.0103		0.0070	0.0077	
1	**Excessive Force**	0.0069	0.0085	0.87	0.0096	0.0106	0.83	0.0039	0.0043	0.72
	Full Delivery	0.0074	0.0109		0.0108	0.0153		0.0044	0.0031	
2	**Excessive Force**	0.0034	0.0031	0.70	0.0034	0.0042	0.48	0.0034	0.0019	0.42
	Full Delivery	0.0038	0.0036		0.0024	0.0022		0.0046	0.0040	
3	**Excessive Force**	0.0127	0.0113	0.11	0.0161	0.0141	0.19	0.0089	0.0057	0.13
	Full Delivery	0.0187	0.0143		0.0244	0.0172		0.0125	0.0060	
4	**Excessive Force**	0.0056	0.0043	0.78	0.0064	0.0046	0.77	0.0044	0.0038	0.19
	Full Delivery	0.0052	0.0052		0.0071	0.0060		0.0028	0.0022	
5	**Excessive Force**	0.0130	0.0098	0.43	0.0133	0.0106	0.30	0.0128	0.0095	0.92
	Full Delivery	0.0113	0.0077		0.0102	0.0068		0.0125	0.0085	
6	**Excessive Force**	0.0104	0.0078	1.3E-03	0.0125	0.0090	0.03	0.0081	0.0061	0.01
	Full Delivery	0.0052	0.0041		0.0073	0.0039		0.0031	0.0032	
7	**Excessive Force**	0.0158	0.0140	0.15	0.0093	0.0053	0.94	0.0230	0.0172	0.09
	Full Delivery	0.0120	0.0075		0.0092	0.0043		0.0151	0.0090	
8	**Excessive Force**	0.0057	0.0063	0.38	0.0078	0.0074	0.09	0.0033	0.0039	0.47
	Full Delivery	0.0047	0.0032		0.0049	0.0026		0.0044	0.0038	
9	**Excessive Force**	0.0123	0.0150	0.44	0.0111	0.0146	0.72	0.0139	0.0165	0.46
	Full Delivery	0.0097	0.0115		0.0094	0.0119		0.0100	0.0114	
10	**Excessive Force**	0.0066	0.0066	0.87	0.0093	0.0075	0.35	0.0035	0.0038	0.47
	Full Delivery	0.0063	0.0056		0.0071	0.0049		0.0053	0.0063	
11	**Excessive Force**	0.0020	0.0034	0.47	0.0031	0.0042	0.60	0.0005	0.0007	0.32
	Full Delivery	0.0015	0.0023		0.0024	0.0028		0.0004	0.0002	
12	**Excessive Force**	0.0012	0.0016	0.79	0.0026	0.0028	0.99	0.0006	0.0006	0.14
	Full Delivery	0.0015	0.0028		0.0027	0.0036		0.0003	0.0001	

Table 49: Full delivery versus excessive force conditions comparison, sensor by sensor. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 50 summarizes the average nonzero pressures region by region for the excessive force and full delivery conditions and compares them with t-tests. The excessive force condition usually has slightly higher pressure but not to a significant extent. The excessive force condition does have significantly higher pressure on the middle finger overall and on the left.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Excessive Force**	0.0087	0.0100	0.37	0.0093	0.0096	0.71	0.0079	0.0104	0.37
	Full Delivery	0.0080	0.0092		0.0089	0.0103		0.0070	0.0077	
Distal	**Excessive Force**	0.0123	0.0121	0.88	0.0119	0.0114	0.64	0.0127	0.0129	0.39
	Full Delivery	0.0121	0.0112		0.0129	0.0131		0.0112	0.0087	
Proximal	**Excessive Force**	0.0063	0.0062	0.07	0.0080	0.0071	0.06	0.0045	0.0043	0.65
	Full Delivery	0.0051	0.0045		0.0061	0.0046		0.0041	0.0042	
Fifth Metacarpal	**Excessive Force**	0.0018	0.0029	0.65	0.0030	0.0038	0.65	0.0006	0.0006	0.08
	Full Delivery	0.0015	0.0024		0.0025	0.0030		0.0003	0.0002	
Thumb	**Excessive Force**	0.0053	0.0067	0.81	0.0069	0.0088	0.91	0.0037	0.0032	0.39
	Full Delivery	0.0057	0.0084		0.0073	0.0123		0.0046	0.0035	
Index	**Excessive Force**	0.0096	0.0095	0.23	0.0115	0.0116	0.25	0.0071	0.0054	0.54
	Full Delivery	0.0125	0.0129		0.0161	0.0156		0.0083	0.0068	
Middle	**Excessive Force**	0.0119	0.0090	0.02	0.0129	0.0096	0.04	0.0109	0.0084	0.22
	Full Delivery	0.0085	0.0069		0.0088	0.0057		0.0081	0.0080	
Ring	**Excessive Force**	0.0107	0.0119	0.18	0.0086	0.0063	0.26	0.0132	0.0158	0.32
	Full Delivery	0.0085	0.0069		0.0071	0.0042		0.0101	0.0088	
Little	**Excessive Force**	0.0097	0.0121	0.39	0.0103	0.0117	0.46	0.0090	0.0131	0.66
	Full Delivery	0.0080	0.0092		0.0083	0.0091		0.0076	0.0094	

Table 50: Full delivery versus excessive force conditions comparison, region by region. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different.

Table 51 summarizes the average nonzero pressures sensor by sensor for the excessive force and full delivery conditions and compares them with t-tests for the residents only to determine if the residents have any significant changes in how they apply pressure between the two conditions. The full delivery condition tends to have slightly higher pressure values on average but not to a significant extent. The excessive force condition does have significantly higher pressures on sensor 6 overall and on the right.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	Excessive Force	0.0078	0.0093	0.54	0.0077	0.0080	0.17	0.0080	0.0107	0.43
	Full Delivery	0.0085	0.0100		0.0100	0.0117		0.0069	0.0073	
1	Excessive Force	0.0046	0.0037	0.50	0.0064	0.0038	0.45	0.0024	0.0025	0.56
	Full Delivery	0.0066	0.0080		0.0103	0.0106		0.0037	0.0038	
2	Excessive Force	0.0038	0.0035	0.87	0.0044	0.0047	0.74	0.0030	0.0007	0.74
	Full Delivery	0.0036	0.0030		0.0035	0.0028		0.0036	0.0033	
3	Excessive Force	0.0148	0.0140	0.17	0.0217	0.0158	0.14	0.0065	0.0048	0.24
	Full Delivery	0.0229	0.0173		0.0337	0.0165		0.0104	0.0066	
4	Excessive Force	0.0070	0.0044	0.59	0.0080	0.0045	0.76	0.0054	0.0045	0.37
	Full Delivery	0.0059	0.0057		0.0071	0.0066		0.0036	0.0025	
5	Excessive Force	0.0107	0.0073	0.48	0.0106	0.0059	0.64	0.0107	0.0090	0.61
	Full Delivery	0.0126	0.0085		0.0121	0.0071		0.0131	0.0099	
6	Excessive Force	0.0107	0.0068	0.01	0.0107	0.0074	0.20	0.0107	0.0071	0.01
	Full Delivery	0.0051	0.0043		0.0074	0.0036		0.0027	0.0037	
7	Excessive Force	0.0140	0.0159	0.32	0.0073	0.0029	0.24	0.0221	0.0218	0.15
	Full Delivery	0.0105	0.0063		0.0094	0.0039		0.0117	0.0083	
8	Excessive Force	0.0051	0.0045	0.93	0.0057	0.0044	0.43	0.0043	0.0050	0.62
	Full Delivery	0.0049	0.0039		0.0043	0.0030		0.0057	0.0049	
9	Excessive Force	0.0080	0.0119	0.87	0.0032	0.0034	0.40	0.0152	0.0170	0.36
	Full Delivery	0.0087	0.0103		0.0078	0.0125		0.0097	0.0076	
10	Excessive Force	0.0042	0.0033	0.30	0.0041	0.0021	0.34	0.0043	0.0046	0.59
	Full Delivery	0.0067	0.0063		0.0068	0.0052		0.0065	0.0076	
11	Excessive Force	0.0013	0.0009	0.87	0.0014	0.0010	0.64	0.0010	0.0012	0.08
	Full Delivery	0.0012	0.0013		0.0017	0.0014		0.0003	0.0002	
12	Excessive Force	0.0008	0.0005	0.83	0.0007	#DIV/0!	#DIV/0!	0.0008	0.0007	0.10
	Full Delivery	0.0010	0.0016		0.0022	0.0024		0.0002	0.0001	

Table 51: Full delivery versus excessive force conditions comparison, sensor by sensor, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. #DIV/0! indicates the value was unable to be calculated due to too few data points.

Table 52 summarizes the average nonzero pressures region by region for the excessive force and full delivery conditions and compares them with t-tests for the residents only to determine whether the residents have any significant changes in how they applied pressure between the two conditions. There are very few significant results. The excessive force condition has significantly higher pressures on the right fifth metacarpal, but the two conditions have significantly the same pressures overall on the fifth metacarpal in general.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Excessive Force**	0.0078	0.0093	0.54	0.0077	0.0080	0.17	0.0080	0.0107	0.43
	Full Delivery	0.0085	0.0100		0.0100	0.0117		0.0069	0.0073	
Distal	**Excessive Force**	0.0107	0.0117	0.29	0.0100	0.0100	0.08	0.0116	0.0138	0.57
	Full Delivery	0.0128	0.0122		0.0152	0.0147		0.0102	0.0081	
Proximal	**Excessive Force**	0.0062	0.0051	0.37	0.0067	0.0052	0.70	0.0055	0.0051	0.42
	Full Delivery	0.0054	0.0050		0.0063	0.0048		0.0045	0.0050	
Fifth Metacarpal	**Excessive Force**	0.0011	0.0008	0.96	0.0013	0.0009	0.91	0.0009	0.0008	0.01
	Full Delivery	0.0011	0.0014		0.0013	0.0015		0.0003	0.0001	
Thumb	**Excessive Force**	0.0042	0.0035	0.57	0.0054	0.0042	0.70	0.0027	0.0017	0.49
	Full Delivery	0.0051	0.0062		0.0072	0.0135		0.0036	0.0034	
Index	**Excessive Force**	0.0111	0.0111	0.28	0.0149	0.0131	0.29	0.0060	0.0044	0.44
	Full Delivery	0.0152	0.0158		0.0207	0.0168		0.0078	0.0063	
Middle	**Excessive Force**	0.0107	0.0069	0.41	0.0107	0.0063	0.72	0.0107	0.0079	0.46
	Full Delivery	0.0091	0.0078		0.0098	0.0072		0.0083	0.0092	
Ring	**Excessive Force**	0.0095	0.0123	0.45	0.0065	0.0037	0.28	0.0132	0.0176	0.32
	Full Delivery	0.0079	0.0060		0.0052	0.0031		0.0090	0.0075	
Little	**Excessive Force**	0.0063	0.0091	0.57	0.0036	0.0028	0.51	0.0098	0.0129	0.66
	Full Delivery	0.0077	0.0086		0.0047	0.0052		0.0081	0.0076	

Table 52: Full delivery versus excessive force conditions comparison, region by region, residents only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Table 53 summarizes the average nonzero pressures sensor by sensor for the excessive force and full delivery conditions and compares them with t-tests for the staff only to determine if the staff had any significant changes in how they apply pressure between the two conditions.

For the excessive force condition, the staff members apply significantly higher pressures on the whole hand overall and on the left because of the significantly higher pressures they apply overall on sensors 6, 8, and 10, and on sensor 10 on the left. Sensors 6, 8, and 10 are proximal sensors, so an increased use of the proximal region causes this relative increase.

Sensor		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Excessive Force**	0.0098	0.0108	0.03	0.0117	0.0112	0.01	0.0079	0.0103	0.63
	Full Delivery	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
1	**Excessive Force**	0.0135	0.0157	0.44	0.0135	0.0157	0.82	0.0054	0.0055	0.84
	Full Delivery	0.0079	0.0127		0.0111	0.0181		0.0050	0.0024	
2	**Excessive Force**	0.0009	0.0001	0.29	0.0009	0.0001	0.49	0.0038	0.0028	0.47
	Full Delivery	0.0040	0.0040		0.0019	0.0019		0.0056	0.0044	
3	**Excessive Force**	0.0078	0.0055	0.14	0.0078	0.0055	0.36	0.0120	0.0058	0.34
	Full Delivery	0.0138	0.0075		0.0128	0.0097		0.0148	0.0046	
4	**Excessive Force**	0.0032	0.0033	0.65	0.0032	0.0033	0.27	0.0024	0.0006	0.89
	Full Delivery	0.0045	0.0045		0.0070	0.0053		0.0022	0.0018	
5	**Excessive Force**	0.0173	0.0156	0.09	0.0173	0.0156	0.08	0.0160	0.0105	0.35
	Full Delivery	0.0097	0.0064		0.0077	0.0057		0.0117	0.0067	
6	**Excessive Force**	0.0154	0.0124	0.01	0.0154	0.0124	0.09	0.0047	0.0025	0.53
	Full Delivery	0.0054	0.0039		0.0072	0.0044		0.0037	0.0025	
7	**Excessive Force**	0.0124	0.0071	0.75	0.0124	0.0071	0.29	0.0242	0.0126	0.34
	Full Delivery	0.0138	0.0085		0.0089	0.0050		0.0187	0.0085	
8	**Excessive Force**	0.0111	0.0104	0.01	0.0111	0.0104	0.08	0.0020	0.0014	0.29
	Full Delivery	0.0044	0.0023		0.0055	0.0020		0.0031	0.0019	
9	**Excessive Force**	0.0229	0.0175	0.12	0.0229	0.0175	0.15	0.0125	0.0184	0.82
	Full Delivery	0.0109	0.0130		0.0114	0.0113		0.0103	0.0155	
10	**Excessive Force**	0.0144	0.0074	4.7E-03	0.0144	0.0074	0.04	0.0023	0.0029	0.65
	Full Delivery	0.0058	0.0047		0.0075	0.0047		0.0035	0.0041	
11	**Excessive Force**	0.0051	0.0059	0.08	0.0051	0.0059	0.46	0.0003	0.0002	0.23
	Full Delivery	0.0017	0.0029		0.0031	0.0039		0.0004	0.0002	
12	**Excessive Force**	0.0046	#DIV/0!	#DIV/0!	0.0046	#DIV/0!	#DIV/0!	0.0003	0.0002	0.69
	Full Delivery	0.0019	0.0035		0.0029	0.0043		0.0003	0.0002	

Table 53: Full delivery versus excessive force conditions comparison, sensor by sensor, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. #DIV/0! indicates the value was unable to be calculated due to too few data points.

Table 54 summarizes the average nonzero pressures region by region for the excessive force and full delivery conditions and compares them with t-tests for the staff only to determine whether the staff members exhibit any significant changes in how they apply pressure between the two conditions. The staff members did apply significantly higher pressures overall on the whole hand and the middle finger as well as, on the left, the whole hand, the proximal region, the middle finger, the ring finger, and the little finger. The staff apply significantly the same amount of pressure on the right index finger between the two conditions.

Region		Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Left Nonzero Average Pressure (MPa)	STDEV.S	T-Test	Right Nonzero Average Pressure (MPa)	STDEV.S	T-Test
Whole Hand	**Excessive Force**	0.0098	0.0108	0.03	0.0117	0.0112	0.01	0.0079	0.0103	0.63
	Full Delivery	0.0074	0.0082		0.0076	0.0083		0.0072	0.0081	
Distal	**Excessive Force**	0.0144	0.0123	0.11	0.0148	0.0129	0.13	0.0140	0.0121	0.48
	Full Delivery	0.0113	0.0100		0.0104	0.0106		0.0122	0.0094	
Proximal	**Excessive Force**	0.0065	0.0075	0.09	0.0100	0.0093	0.02	0.0031	0.0022	0.48
	Full Delivery	0.0048	0.0039		0.0060	0.0043		0.0037	0.0032	
Fifth Metacarpal	**Excessive Force**	0.0024	0.0041	0.57	0.0050	0.0051	0.37	0.0003	0.0002	0.18
	Full Delivery	0.0018	0.0031		0.0031	0.0039		0.0004	0.0002	
Thumb	**Excessive Force**	0.0066	0.0094	0.85	0.0093	0.0138	0.72	0.0046	0.0041	0.65
	Full Delivery	0.0061	0.0097		0.0070	0.0140		0.0053	0.0035	
Index	**Excessive Force**	0.0072	0.0058	0.34	0.0059	0.0050	0.21	0.0088	0.0067	0.99
	Full Delivery	0.0095	0.0078		0.0102	0.0084		0.0088	0.0073	
Middle	**Excessive Force**	0.0138	0.0115	0.01	0.0164	0.0132	0.01	0.0112	0.0097	0.30
	Full Delivery	0.0077	0.0058		0.0075	0.0050		0.0079	0.0065	
Ring	**Excessive Force**	0.0124	0.0114	0.21	0.0117	0.0083	0.05	0.0131	0.0145	0.70
	Full Delivery	0.0092	0.0078		0.0072	0.0041		0.0113	0.0101	
Little	**Excessive Force**	0.0138	0.0143	0.11	0.0186	0.0133	0.03	0.0082	0.0142	0.83
	Full Delivery	0.0083	0.0100		0.0095	0.0087		0.0070	0.0115	

Table 54: Full delivery versus excessive force conditions comparison, region by region, staff only. The distribution of applied pressures is illustrated by coloring from red (highest) to green. A light green t-test cell indicates that the compared values are significantly different. A light yellow t-test cell indicates that the compared values are significantly the same.

Part 4 - Occurrence of Peak Values

The Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) could only measure pressures in a range of 0 to 20 psi (0 to 0.14 MPa). Thus, whenever a value of 20 psi is registered, it is possible that value is actually some value higher than 20 psi. To investigate this possibility, the data were analyzed to determine how often the 20 psi value actually occurred. Appendix A.5 contains the MATLAB scripts for this analysis.

How many 20 psi values out of all the nonzero values for that dataset over time, or the '% maxed' is presented in Tables 55, 56, and 57 for the traction only, excessive force, and full delivery conditions, respectively. Of note, only the left sensors 3 and 1 ever maxed out. Sensor 3 is the distal sensor on the index finger that often has high values. Sensor 1 is the distal sensor on the thumb. Not all of the subjects even reach 20 psi, and of those who reach 20 psi, they do not necessarily reach 20 psi on every trial.

Dataset	Sensor	# Of Points Maxed Out	Out Of	% Maxed
subject02trial01tractiononly	*Left Sensor 3*	37	141	26.2
subject10trial02tractiononly	*Left Sensor 3*	10	59	16.9
subject10trial03tractiononly	*Left Sensor 3*	8	33	24.2
subject12trial02tractiononly	*Left Sensor 3*	2	70	2.9
subject10trial01tractiononly	*Left Sensor 3*	1	68	1.5
subject07trial02tractiononly	*Left Sensor 1*	1	37	2.7
subject07trial03tractiononly	*Left Sensor 1*	1	37	2.7

Table 55: % maxed for the traction only condition.

Dataset	Sensor	# Of Points Maxed Out	Out Of	% Maxed
subject10trialbad	*Left Sensor 3*	4	32	12.5
subject02trialbad	*Left Sensor 1*	4	83	4.8

Table 56: % maxed for the excessive force condition.

Dataset	Sensor	# Of Points Maxed Out	Out Of	% Maxed
subject10trial02fulldelivery	***Left Sensor 3***	20	58	34.5
subject02trial01fulldelivery	***Left Sensor 1***	20	108	18.5
subject10trial03fulldelivery	***Left Sensor 3***	14	64	21.9
subject01trial02fulldelivery	***Left Sensor 3***	11	74	14.9
subject02trial03fulldelivery	***Left Sensor 1***	2	81	2.5
subject07trial02fulldelivery	***Left Sensor 1***	1	22	4.5

Table 57: % maxed for the full delivery condition.

The dataset with the highest % maxed is subject 10 trial 02 full delivery Left Sensor 3 with a % maxed of 34.5%. Thus, if the 20 psi values in that dataset were actually higher values, that dataset would be the one most likely to be significantly changed. Replacing all the 20 psi values in that dataset, while leaving the other values unchanged, with 32 psi (0.22 MPa) causes the two datasets to be significantly different with a t-test value of 0.05, indicating significance. When the 20 psi values are replaced with a value higher than 32 psi, such as 35 psi (0.24 MPa), the significance of the difference increases to a t-test value of 0.02, so higher values will only increase the significance of the difference.

Discussion

The Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] results indicate that the fingers apply high pressures, particularly the middle, ring, and index fingers. Thus, the fingers require sensors on them and cannot be neglected. The palm/fifth metacarpal area applies low pressures, almost negligible, suggesting that this area does not need to be densely outfitted with sensors. The thumb also applies very low pressures, but due to its unique role in manipulating objects, the thumb should still be outfitted with sensors. The left hand tends to apply higher pressures than the right hand, but these pressures are not significantly higher. Most of the subjects were right-handed, so hand dominance does not seem to dictate which hand applies the most pressure. The infant mannequin facing left or right may have had more of an impact on which hand the obstetrician uses to apply the most pressure due to positional constraints. The left hand was usually on the top and thus would be applying more pressure than the right hand, which was usually on the bottom. According to the pressure film, the staff members apply significantly more pressure with their little fingers than the residents, which is a trend that appears in some of the glove sensor data.

For the downward traction only condition, the left hand again tends to have higher pressures but not often significantly so. The left hand provides significantly higher pressures on sensors 3, 6, and 7, which are all located on the fingers. Many sensors indicated pressures different from each other, which indicates that the hand applies different pressures with the different hand areas, as opposed to one single pressure across the area of the whole hand. This finding means that many sensors are necessary to accurately capture pressure distributions across the hand and that using fewer sensors would reduce accuracy. The index, ring, and middle fingers provide the highest pressures. The fifth metacarpal and the thumb are associated with the lowest pressures. The distal region produces high pressures in general. These pressures are significantly higher than the proximal region, which apply low pressures, indicating that intermediate sensors may be needed. There is a large pressure change moving from the proximal to distal regions. Thus, it would be incautious to make naïve assumptions about the behavior of pressures in the intermediate region without first making measurements in that region.

Comparing the residents and the staff, the residents apply significantly higher pressures for the average of the whole hand. This outcome is due mainly to significantly higher pressures on sensor 3, the distal pressure sensor on the index finger. The residents also produce significantly higher pressures with the distal region in general and the right fifth metacarpal. However, the staff apply significantly higher pressures on the left little finger, as is noted with the pressure film results. These results may suggest that the residents have a more fingertip-based technique for applying pressure. However, the staff members, due to their experience, apply pressure in a more balanced fashion, instead of neglecting the little finger.

In the excessive force case, again, the left hand tends to apply higher pressure but not significantly so. The right hand applies significantly higher pressures on sensor 7, the distal sensor on the ring finger. Again, the sensor measurements are significantly different from the one another, suggesting that decreasing the number of sensors would decrease accuracy and should thus be avoided. The regional results show that the left proximal region applies significantly higher pressures than the right. Staff members generally apply higher pressures than the residents with significantly higher pressures for the left hand, sensor 9, and sensor 10. Sensors 9 and 10 are on the little finger, where the staff again apply significantly higher pressures than the residents. Thus, the trend, where staff members applying significantly higher pressures with the little finger than the residents, is evident again. During the testing, residents seemed nervous and hesitant during the excessive force condition, perhaps concerned with being overly enthusiastic in modeling improper form. The staff members, on the other hand, seemed quite excited and willing to model improper form as a teaching experience. This attitude difference likely explains why the staff members use higher pressures for the excessive force condition than the residents.

For the full delivery condition, the left hand actually provides significantly higher pressures than the right overall (for the right and left hands averaged) and on sensors 3, 4, 6, and 11. Significantly higher pressures with the right hand are evident on sensor 7. Many of the sensors indicate significantly different pressures when compared to each other. This observation provides additional support for the idea that many sensors are needed to accurately capture the pressure variability and that few sensors, if any, are redundant. Significantly higher pressures on the left hand are associated with the proximal region, fifth metacarpal, and index finger. The ring finger on the right hand provides significantly higher pressures.

As with downward traction, the residents tend to apply higher pressures than the staff, though rarely significantly so. The residents apply significantly higher pressures indicated by sensor 3 on the left hand, the distal sensor on the index finger. The staff members apply significantly higher pressures with the ring finger of the right hand at sensor 7. The residents apply significantly higher pressures on the left distal region, the index finger overall, and the left index finger. The staff members apply significantly higher pressures with the fifth metacarpal. Again, this distal emphasis suggests a more fingertip-based approach by the residents. The tendency for staff members to make more use of the fifth metacarpal also points to their learning through experience to use more of the hand.

Of note, in all three conditions: downward traction only, excessive force, and full delivery, sensors 11 and 12, on the fifth metacarpal, tend to indicate significantly lower pressures than most of the other sensors and often had similar values to each other. Thus, the fifth metacarpal may not require two sensors and perhaps only one if the budget for sensors is an issue in future designs.

The comparison of the Fujifilm Pressure Measurement Film Prescale [Two-Sheet Type for Extreme Low Pressure (4LW)] and the Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical) results suggest that the sensors are probably mostly placed and the readings are probably accurate. Both methods show the index, middle, and ring fingers providing the highest pressures, albeit in different orders, and the palm/fifth metacarpal and thumb applying the lowest pressures. If there were more sensors on the gloves, the effective resolution would increase and any discrepancies of rank order between the two measurement methods would likely be eliminated.

When results for the excessive force condition are compared to the downward traction only condition, the former is expected to produce significantly higher pressures. The excessive force condition usually provides higher average pressures than the downward traction only condition; but the difference is usually not significant. The excessive force condition provided significantly higher pressures on overall (right and left averaged) sensor 6, left sensor 6, right sensor 6, overall sensor 9, and left sensor 12. Sensor 6 is the proximal sensor on the middle finger. Sensor 9 is the distal sensor on the little finger. Sensor 12 is the most proximal sensor on the fifth metacarpal. The excessive force condition also provides significantly higher pressures on the overall and left fifth metacarpal and the overall and left middle finger.

Looking at the residents only, they produce higher averages for the traction only condition in some cases but not significantly so. The residents apply significantly higher pressures for the excessive force condition at sensor 6 overall and on the right and on the fifth metacarpal overall. Staff members, however, apply significantly higher pressures with the whole hand overall and on the left, sensor 1 overall, sensor 6 overall, right sensor 7, sensor 9 overall and on the left, and sensor 11 overall. The staff may apply significantly more pressure during the excessive force condition when compared to the downward traction only condition because they are more willing to model improper practice for a didactic goal. However, when considering both the residents and staff as a whole, high pressures alone may not constitute all the elements of improper form, given that the excessive force condition does not generally provide a significantly higher whole hand pressure.

Some obstetricians mentioned that, during proper downward traction, the facet joints of the spine in the neck will lock, moving the shoulder down without bending the neck. This locking of the spine prevents tension on the brachial plexus and prevents damage. With improper form, the facet joints do not lock, and there will be large deflections of the spine, causing the brachial plexus to be stretched and perhaps tear or break. Figure 14 depicts both proper and improper procedure and the consequences thereof. Pressure sensors alone cannot capture what positioning the obstetrician performs with the infant mannequin, and it is possible that deflections caused by poorly performed positioning also contributes to brachial plexus injuries, in addition to pressure. If this is the case, it would explain why pressure alone does not show large differences between the downward traction and excessive force conditions. The need to capture gestures performed with the hands is an argument for improvement in glove technology. For example, the next generation of gloves might include acceleration sensors of the sort used in sign language gloves for gesture capture. Then, gloves would be able to record gestures as well as pressure, and a study could investigate whether the excessive force condition involves more large deflections than the downward traction condition.

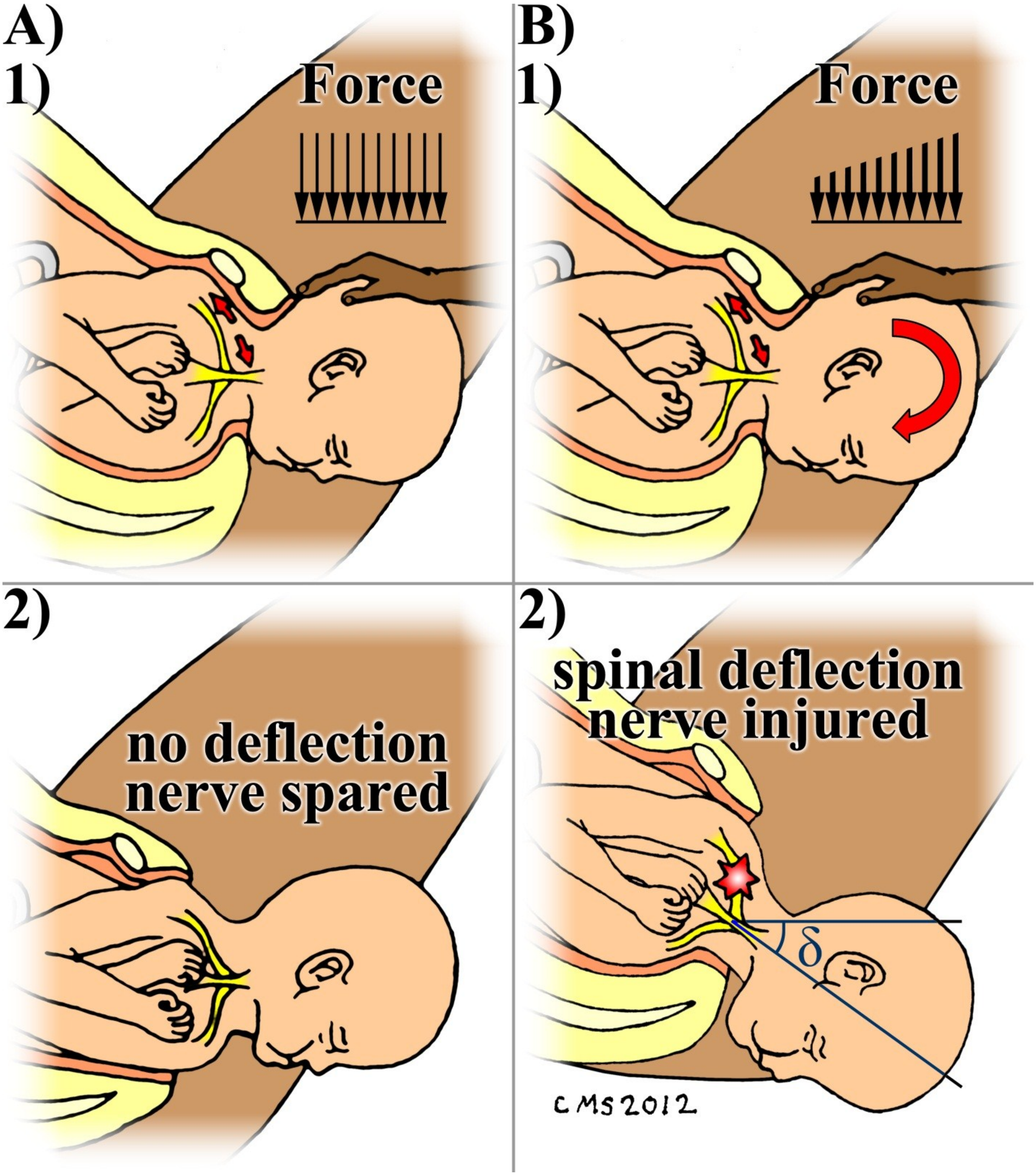

Figure 14: A) Proper downward traction leads to 1) the facet joints of the neck locking and 2) the shoulder displacing downward with no damage to the brachial plexus. B) Improper downward traction leads to 1) the facet joints of the neck do not lock, leading to 2) large deflections of the head, causing the brachial plexus to suffer injuries.

Consider now a comparison of the downward traction only condition to the full delivery condition. The former condition is expected to provide higher pressures than the full delivery condition, because the delivery after the downward traction phase is thought to involve less pressure. Traditionally, the full weight of the baby is not expected to cause large pressures. However, the results show that the averages for the two conditions are similar with few significant differences. Full delivery is associated with significantly higher pressures on the right sensor 3, the fifth metacarpal overall, and the left fifth metacarpal. The residents exhibit few significant differences when the results of the downward traction only condition are compared to the full delivery condition. Full delivery produces significantly higher pressures on left sensor 11, but traction only provides significantly higher pressures on the right fifth metacarpal and the left ring finger. For the full delivery condition, staff members apply higher pressures at the right sensor 3, overall sensor 7, right sensor 7, right sensor 12, the distal region overall, the right distal region, and with the right fifth metacarpal. The downward traction only condition generally does not result in significantly higher pressures as compared to the full delivery condition. Moreover, the full delivery condition sometimes indicates significantly higher pressures than the downward traction only condition. These results are one more indication that pressure alone does not tell the whole story and supports the concept of integrating acceleration sensors into future designs to capture gestures. Also, in the full delivery condition, the physician supports the weight of the full infant, which may end up being more pressure than the physician applies during downward traction. Future studies could extract out the segment after the downward traction phase to examine how much pressure the infant in the physician's hands causes.

Finally, the excessive force and full delivery conditions are compared. If excess pressure is the only factor that causes damage, the excessive force condition should result in higher pressures than the full delivery condition. However, the results show that the two conditions are rarely significantly different with fairly similar averages. The excessive force condition does indicate significantly higher pressures with sensor 6 overall, left sensor 6, right sensor 6, the middle finger overall, and the left middle finger. For the residents only, the excessive force condition indicates significantly higher pressures with sensor 6 overall, right sensor 6, and the right fifth metacarpal. For the staff only, the excessive force condition actually does result in significantly higher pressures for the whole hand overall, the left whole hand, sensor 6 overall, sensors 8 overall, sensor 10 overall, left sensor 10, the left proximal region, the middle finger overall, the left middle finger, the left ring finger, and the left little finger. However, as noted, staff members are much more enthusiastic about modeling poor practice. In general, the excessive force condition does not produce decisively higher pressures than the full delivery condition, which again supports a design that includes accelerometers.

As a general comment, some of the staff members mentioned that they might use more pressure than the residents, because by the time a staff member is called in, the delivery may already be at a critical stage where decisive action is required. Commonly, the residents handle lower risk cases. Overall, however, the results do not show large differences between the residents and staff, which is reassuring, because it means that the residents are reasonably well trained as compared to the staff and that the staff do not deviate significantly from what they learned as residents.

There is a problem of the sensors 'maxing out', that is to say, reaching the maximum value of 20 psi (0.14 MPa), when the actual value is somewhat higher. As Tables 50, 51, and 52 showed, only the left sensors 3 and 1 ever reached that 20 psi value. This was not the case with every subject. Moreover, of the subjects who produced pressures greater than the maximum, they did not necessarily do so in every trial. This trend seems to indicate that pressures exceeding 20 psi are rare.

The dataset that was most likely to be influenced by pressures higher than 20 psi was analyzed further. Sensitivity tests indicated that only when 20 psi readings were replaced with 32 psi (0.22 MPa) values or higher were significant differences evident between the original 20 psi and the artificial 32 psi datasets. Thus, if many values 32 psi or higher are being registered, it would potentially reduce the accuracy of the pressure analysis. If the cost difference would not be prohibitive, the next generation of gloves could use sensors that register 0 to 35 psi (0.24 MPa) to try to avoid this problem. However, given that exceedances were localized to a few sensors in a few trials, the impact on the data should not be too severe, if it is infeasible to use sensors with a higher pressure. It should simply be noted that the data can be underestimated with regards to the true values.

Using these results, some suggestions about future design choices can be formulated. The palm tends to produce extremely low pressure compared to the rest of the hand, which means that not placing many sensors on the palm is a justified design choice. Indeed, sensors 11 and 12 tend to have very similar values, suggesting they may be redundant. The thumb exerts the second lowest pressures, usually significantly lower than the average of the whole hand. Even the little finger tends to apply significantly higher pressure than the thumb. However, sensor 1 is located on the thumb; and it is one of only two sensors that ever peak out and is important for many gestures. Thus, the thumb should still include sensors.

The distal region almost always provides significantly higher pressures than the proximal region, suggesting that intermediate sensors may be necessary to capture the correct pressure distribution. Taking all of these factors into account, Figure 15 suggests one possibility for improving the sensor layout. Because the fingers tend to apply higher pressure, sensors are provided for the intermediate region of the fingers. The sensor distribution on the palm is sparse because the palm generally applies low pressures. If the sensors budget cannot afford that many sensors, some of the sensors on the palm and the intermediate sensor on the little finger would be obvious choices for removal. In addition, future gloves should probably be made of a comfortable, stretchy, thin material, such as Lycra. The thicker material on the existing glove , drew complaints from the subjects. A thinner, more breathable material would facilitate wearing sterile disposable gloves over the sensor gloves, as well, which might allow the gloves to be used during actual deliveries. Another useful design feature would be to make the gloves be wireless or at least fasten the cabling down to make them less obtrusive. Eventually, several glove sizes could be designed to fit different size hands.

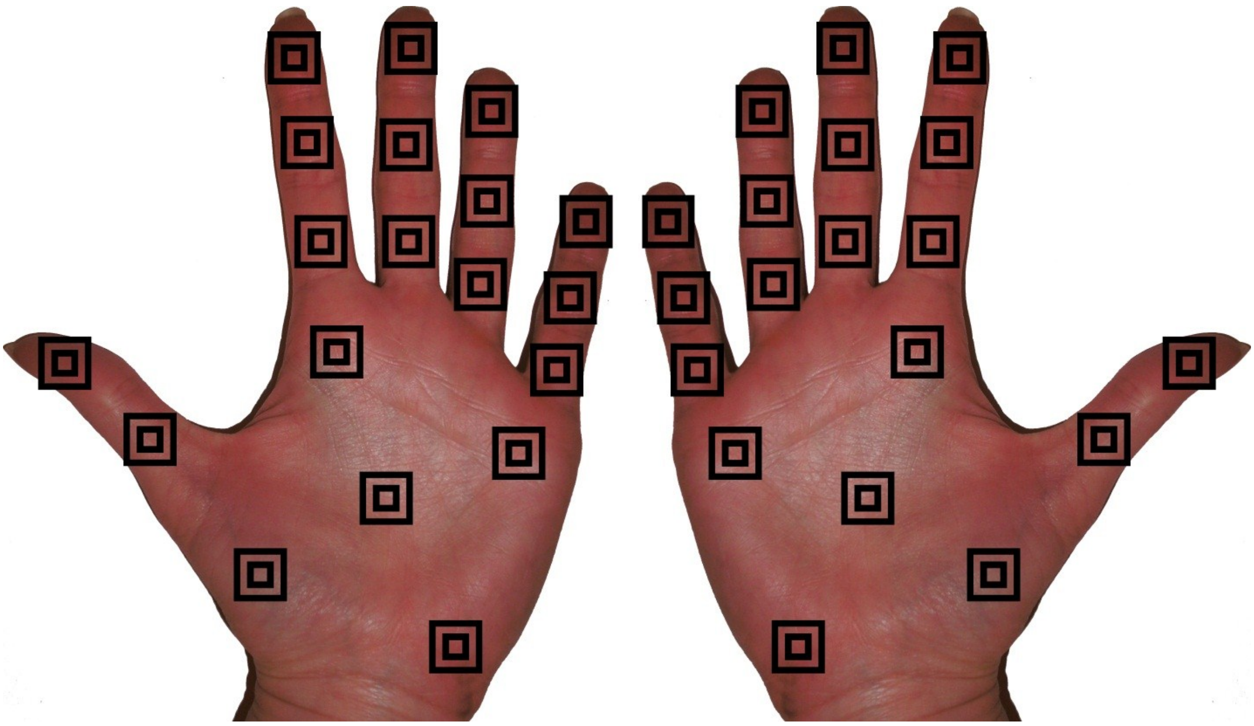

Figure 15: Possible future sensor layout.

This study had a number of sources of error. The attendant who operated the infant mannequin could not provide standardized resistance. The infant mannequin's left/right orientation was also not standardized or documented. Not all of the data was gathered at the same location or under the same temperature and relative humidity conditions, which could have affected the interpretation of the pressure-film measurements. The gloves did not fit all of the obstetricians the same way, so the sensors may not have ended up on the same hand regions for all the subjects. In addition, the gloves have problems with sensors 9-12 tending to roll off the side of the hand. Thus, pressures measured with those sensors may be lower than actual pressures generated at nominal sensor positions. Finally, both the pressure film and the glove sensors can max out, which could have led to the readings being too low.

This study has as strengths that it used two measurement methods, both the pressure film and the glove sensors, to validate the gloves. The study was able to compare residents and staff. The study was also able to examine three different conditions.

Chapter Four: Summary

Summary of Study

This study identifies important gaps in knowledge related to pressures provided by obstetricians during regular and shoulder dystocia deliveries. Moreover, the potential benefits of well-known delivery maneuvers in reducing forces and fetal injuries are also not well understood. The present study is the first step in a larger project designed to contribute to knowledge of hand behaviors and especially circumstances capable of creating brachial plexus injuries. Specific objectives of the project are to determine the pressures that might be applied during delivery, to validate the pressure-sensing gloves, and to establish their efficacy in research and teaching.

The approach involves an analysis of hand pressures applied by obstetricians in mock deliveries. The subjects are obstetricians, both residents and staff, recruited from the Kansas University Medical Center. Hand pressure measurements are conducted as the clinicians perform mock deliveries with a Laerdal PROMPT Birthing Simulator. The experimental design involved two pressure measurement strategies. Force Sensitive Applications (FSA) pressure sensitive gloves (Vista Medical), which provide discrete pressure measurements with time. Each glove has twelve pressure sensors on the palmar side of the hand, two on each digit, roughly distal and proximal, and another two sensors on the fifth metacarpal (the palm proximal to the digitus minimus). Fujifilm Pressure Measurement Film also is used to provide time-integrated measurements of where pressure is applied as quantitative pressure maps.

Each subject was asked to participate in three major conditions that are monitored for pressures. Some conditions involved several trials or variations. For the first two trials of

Condition 1, each subject was monitored using the gloves with sensors. He/she was asked to perform solely downward traction on the shoulder and head of the infant mannequin during a simulated shoulder dystocia delivery but not the complete delivery. These two methods establish the magnitude of pressures generated with downward traction and where these pressures were distributed on the hands. The third trial of the Condition 1 involved both the pressure sensitive gloves and the pressure measurement film.

For Condition 2, of which there was only one trial, the subject simulated a shoulder dystocia delivery that would model improper, dangerous practice with excessive force sufficiently large to cause a brachial plexus injury. The subject wore pressure-sensing gloves, explained what he or she was performing, and was also videotaped for this trial. This condition is designed to determine dangerous pressures that might be measured by the gloves. Condition 3 includes three trials. Subjects were instructed to proceed with a full delivery of the infant mannequin. The subject again wore pressure-sensing gloves and was videotaped. Data from the sensors of the gloves are processed to provide non-zero means for each sensor. Use of the nonzero mean ensured that data points only are considered when pressure is actually being exerted.

Results indicate that the two measurement techniques compare well in capturing the spatial distribution of pressures across the hands. Both film and sensor data for Condition 1, Trial 3, downward traction with a simulated shoulder dystocia delivery, show that pressure is exerted primarily with the middle, index and ring fingers, albeit in different orders. If there were more sensors on the gloves, the effective resolution would increase and any discrepancies of rank order between the two measurement methods would likely be eliminated. Pressures due to the thumb and the palm are significantly smaller. Average nonzero pressures produced by the left hand are higher than the right, but not significantly so. The pressure-film data indicates that pressures applied by the resident and staff subgroups are comparable, except for the left hand where staff members apply significantly higher pressure with the little finger. The sensor data also suggest that staff distribute pressures more evenly across the hand.

The excessive force trial with Condition 2 simulates a situation where pressures are sufficiently high to cause injury. With some exceptions, the broad distribution of pressures across the hand is similar to the traction only case. Significantly, the highest average nonzero pressures are produced by the middle finger. Again, on the left hand the highest pressures are evident with sensors 3 and 5 at the ends of the index and middle fingers. These are significantly higher than sensors 2 and 11 on the lower thumb and the edge of the palm. On the right hand the significant pressures are exerted by the end of the ring finger at sensor 7. The staff members as a subgroup create significantly higher pressures with their left hand and distal areas.

Condition 3 is a mock full delivery. Analysis of the data shows that pressures on the sensors with Condition 3 are higher, but not significantly different than Condition 1, traction only.

The sensors on the glove cover a range from 0 to 20 psi (0 to 0.14 MPa). There were times during all three delivery conditions when pressures on the left thumb (sensor 1) and index finger (sensor 3) exceeded the maximum for the sensors. Not every subject exceeded the maximum, however. Moreover, of the subjects who produced pressures greater than the maximum, they did not necessarily do so in every trial. This result seems to indicate that exceeding the maximum is rare.

An analysis suggests that when pressures far exceed the sensor range, for example 32 psi, the accuracy of the averaging is influenced, suggesting that perhaps the sensor range should be improved in newer designs. Other important design changes would include increasing the numbers of sensors, especially for the intermediate region of the hand.

Conclusions and Recommendations

This study set out to learn more about the distribution of pressures on the hand during a mock delivery and the potential of using pressure-sensing gloves to accurately measure those pressures. The key conclusions of the study follow here.

It can be concluded from the measurements and analyses that pressures vary markedly in time and across the hands. The average nonzero pressures throughout the experiments indicate that on the left hand the tips of the index finger and the middle finger create the largest pressures. Pressures related to these distal sensors on the thumb and the index finger exceed the upper limits of the sensors on occasion, but the thumb generally tends to apply significantly lower pressures than most of the other regions. The palm/fifth metacarpal areas apply almost low or negligible pressures. The proximal region also tends to apply low pressures. On the right hand, the finger tips produce the largest non-zero average pressures, but the dominance shifts to the ring finger and the middle finger. There are no cases where sensors on the right hand exceed the pressure maximum for the sensors.

The pressure film and glove sensors provide different kinds of measurements. The pressure film measures continuously across the hand but provides only an average of time effects. The glove sensors provide a significant record in time but limited spatially to a relatively small number of sensors. Yet, qualitative comparisons show broad similarities in the patterns of pressures just described. These favorable comparisons lead to the conclusion that pressure sensing gloves have the potential to be developed for learning about pressures distributions across the hands. However, it also can be concluded that there are significant opportunities to optimize the distribution of sensors on the glove to make more resolved measurements in areas where pressures are the highest. Specific recommendations in this respect follow in a latter section.

There are surprising hints in the data to suggest that experience does alter the way the hands are used in a delivery. For example, with the traction only condition, residents use significantly higher pressure in the distal regions than the staff. The conclusion is that through experience staff members have learned to distribute pressures across their entire hand.

Another surprise is that differences expected with the various conditions may not be well represented with the pressure data. For example, from the pressure measurements alone, the excessive force condition is not much different than the full delivery condition and the downward traction only condition. The residents do produce higher averages for the traction only condition in some cases but not significantly so. The staff may apply significantly more pressure during the excessive force condition when compared to the downward traction only condition because they are more willing to model improper practice for a didactic goal. However, when considering both the residents and staff as whole, the elements of improper form represented by the excessive force condition may simply not be well represented by pressure.

A possible explanation is that pressure sensors alone cannot capture the nuances of the positioning of the infant mannequin by the obstetrician. This theory would explain why pressure alone does not show large differences between the downward traction and the excessive force conditions. The need to capture gestures performed with the hands is an argument for improvement in glove technology. For example, the next generation of gloves might include acceleration sensors of the sort used in sign language gloves for gesture capture. Such a design could test the hypothesis that deflections caused by poor positioning, in addition to pressure, also contribute to brachial plexus injuries.

Several methodological issues should be mentioned as problems. There is general difficulty in maintaining similar conditions with the mock birthing simulator. Individual trials can be quite different because the resisting forces are provided by an operator. This approach, for example, contrasts with that provided Allen's group [31] where the system creates a consistent expulsive pressure. It is likely that the Laerdal simulator could be modified to provide a more consistent and reproducible back forces. Another is that the gloves themselves were the cause of some problems. For example, the gloves did not fit all subjects the same way, causing sensors to monitor slightly different positions of the hand. Also, sensors 9-12 tend to roll off the side of the hand. Thus, pressures measured with those sensors may be lower than actual pressures generated at nominal sensor positions.

Further Study

Studies of the literature suggest there remains great potential for studies in the area of shoulder dystocia and complicated deliveries in general. The association of dystocia with heavier mothers and fetuses suggests that these problems will persist. The development of pressure sensing gloves is a critical part of understanding how pressures are transmitted by the hands.

It is recommended that for follow on studies with the present glove-sensing technology that the location of sensors be optimized to better match the tendency for higher pressures to be generated in the distal parts of both hands. Figure 15 provides an example of an improved sensor distribution. In the future, it is likely that gloves will be available with many more sensors. Gloves also should be made from a comfortable, stretchy, thin material, such as Lycra. A thinner, more breathable material would facilitate wearing sterile disposable gloves over the sensor gloves, as well and expand their potential usefulness.

Opportunities would also appear to exist in expanding the types of sensor carried by a glove. For example, the next generation might include acceleration sensors of the sort used in sign language gloves for gesture capture. Thus, gloves would be able to record gestures as well as pressure. With some improvement to the Laerdal simulator, these gloves could be used to test a hypothesis that brachial plexus injuries may be due to both excess pressures and poor positioning of the obstetrician's hands on the infant.

Because of the great difficulty in making measurements with human subjects, considerable knowledge in understanding complex problems of delivery has come from experiments with sophisticated experimental systems, for example [31] and [35]. Beyond this experimental work, future studies could well return to a next generation of mathematical-based approaches.

In the future, when a new generation of gloves have been designed and proper and improper procedure have been documented, it may be possible for medical students to wear the gloves while performing simulated deliveries and receive real time feedback on their performance. For example, if a student performs an excessive deflection, a monitor screen could flash red and a buzzing tone could be sounded. Thus, in the future, these gloves could be used as a teaching tool as well as a research tool.

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Appendix

A.1: Research consent form.

RESEARCH CONSENT FORM
Assessing Hand Posture and Pressures in Obstetricians Performing Mock Deliveries on a Mannequin

Protocol #

You are being asked to join a research study because you are a physician trained in obstetrics. The main purpose of research is to create new knowledge for the benefit of future patients and society in general. Research studies may or may not benefit the people who participate. You do not have to participate in this research study.

Research is voluntary, and you may change your mind at any time. There will be no penalty to you if you decide not to participate, or if you start the study and decide to stop early. Either way, you can still get medical care and services at the University of Kansas Medical Center (KUMC).

This consent form explains what you have to do if you are in the study. It also describes the possible risks and benefits. Please read the form carefully and ask as many questions as you need to, before deciding about this research.

You can ask questions now or anytime during the study. The researchers will tell you if they receive any new information that might cause you to change your mind about participating.

This research study will take place at the University of Kansas Medical Center (KUMC) and University of Kansas Lawrence with Dr. Sara Wilson as the researcher. About 30 people will be in the study.

BACKGROUND
The goal of this study is to identify the ranges of pressures and motions used by a physician trained in obstetrics during delivery of a baby. Unusual conditions such as shoulder dystocia or macrosomia may sometimes require additional efforts by either the physician or mother to bring about delivery. We would like to develop a device that can measure these pressures accurately to provide feedback to practitioners or emergency providers. In order to do this, we need to have data on the range of pressures and hand postures that may be used during delivery.

PURPOSE
By doing this study, researchers hope to learn the range of pressures and hand postures in order to better design a tool to assess and train physicians and others involved in delivery.

PROCEDURES
If you are eligible and decide to participate in this study, your participation will last

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approximately 30-60 minutes and the study will be completed in one session. Your participation will involve wearing gloves instrumented with pressure sensing electronic pads in the palm and fingers, pressure sensing plastic film on the palm and fingers, and/or motion sensing (accelerometers) on the fingers and back of the hands. These devices passively measure how much pressure you exert with your fingertips and the posture your hands assume.

With the gloves on, you will be asked to perform a series of delivery maneuvers on a plastic training mannequin including delivery of the head, trunk rotation, shoulder dystocia release maneuvers, breech birth delivery, and cesarean delivery.

RISKS
There are few if any risks involved in this experiment. Data will be collected on the pressures you exert but this data will be de-identified. There may be other risks of the study that are not yet known.

NEW FINDINGS STATEMENT
You will be told about anything new that might change your decision to be in this study. You may be asked to sign a new consent form if this occurs.

BENEFITS
Researchers hope that the information from this research study may be useful in developing tools to assess pressures and delivery methods in the delivery room. Such a tool could be used to train new practitioners.

ALTERNATIVES
Participation in this study is voluntary. Deciding not to participate will have no effect on the care or services you receive at the University of Kansas Medical Center or your employment.

COSTS
There is no cost for being in the study.

PAYMENT TO SUBJECTS
There is no payment for this study.

IN THE EVENT OF INJURY
If you have a bodily injury as a result of participating in this study, treatment will be provided for you at the usual charge. Treatment may include first aid, emergency care and follow-up care, as needed. Claims will be submitted to your health insurance policy, your government program, or other third party, but you will be billed for the costs that are not covered by the insurance. You do not give up any legal rights by signing this form.

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INSTITUTIONAL DISCLAIMER STATEMENT

If you think you have been harmed as a result of participating in research at the University of Kansas Medical Center (KUMC), you should contact the Director, Human Research Protection Program, Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160. Under certain conditions, Kansas state law or the Kansas Tort Claims Act may allow for payment to persons who are injured in research at KUMC.

CONFIDENTIALITY

The researchers will protect your information, as required by law. Absolute confidentiality cannot be guaranteed because persons outside the study team may need to look at your study records. The researchers may publish the results of the study. If they do, they will only discuss group results. Your name will not be used in any publication or presentation about the study.

Your health information is protected by a federal privacy law called HIPAA. In this study, no health information will be collected.

All study information that is sent outside KU will have your name and other identifying characteristics removed, so that your identity will not be known. Because identifiers will be removed, your health information will not be re-disclosed by outside persons or groups and will not lose its federal privacy protection.

QUESTIONS

Before you sign this form, Dr. Wilson or other members of the study team should answer all your questions. You can talk to the researchers if you have any more questions, suggestions, concerns or complaints after signing this form. If you have any questions about your rights as a research subject, or if you want to talk with someone who is not involved in the study, you may call the Human Subjects Committee at (913) 588-1240. You may also write the Human Subjects Committee at Mail Stop #1032, University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160.

SUBJECT RIGHTS AND WITHDRAWAL FROM THE STUDY

You may stop being in the study at any time. Your decision to stop will not prevent you from getting treatment or services at KUMC. The entire study may be discontinued for any reason without your consent by the investigator conducting the study.

CONSENT

Dr.Wilson or the research team has given you information about this research study. They have explained what will be done and how long it will take. They explained any inconvenience, discomfort or risks that may be experienced during this study.

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By signing this form, you say that you freely and voluntarily consent to participate in this research study. You have read the information and had your questions answered.
You will be given a signed copy of the consent form to keep for your records.

____
Print Participant's Name

______________________________ ______ ______________
Signature of Participant Time Date

____
Print Name of Person Obtaining Consent

______________________________ ______________
Signature of Person Obtaining Consent Date

HSC #: 13134
Approval Date: 03/14/12 to 03/13/13
Assurance #: FWA00003411

A.2: MATLAB script for interpreting pressure-film measurements.

```
% get rid of old variables and clean up window
clear all;
close all;
clc;

% loads in files provided the correct file folder is selected
names={'1-L',
  '2-L',
  '3-L',
  '5-L',
  '7-L',
  '8-L',
  '9-L',
  '10-L',
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  '12-L',
  '1-R',
  '2-R',
  '3-R',
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  '7-R',
  '8-R',
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  '12-R',
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```

```
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'10-R-thumb',
'11-R-thumb',
'12-R-thumb',
'1-L-index',
'2-L-index',
'3-L-index',
'5-L-index',
'7-L-index',
'8-L-index',
'9-L-index',
'10-L-index',
'11-L-index',
'12-L-index',
'1-R-index',
'2-R-index',
'3-R-index',
'5-R-index',
'7-R-index',
'8-R-index',
'9-R-index',
'10-R-index',
'11-R-index',
'12-R-index',
'1-L-middle',
'2-L-middle',
'3-L-middle',
'5-L-middle',
'7-L-middle',
'8-L-middle',
'9-L-middle',
'10-L-middle',
'11-L-middle',
'12-L-middle',
'1-R-middle',
'2-R-middle',
'3-R-middle',
'5-R-middle',
'7-R-middle',
'8-R-middle',
'9-R-middle',
'10-R-middle',
'11-R-middle',
'12-R-middle',
'1-L-ring',
'2-L-ring',
'3-L-ring',
'5-L-ring',
'7-L-ring',
'8-L-ring',
'9-L-ring',
```

```
  '10-L-ring',
  '11-L-ring',
  '12-L-ring',
  '1-R-ring',
  '2-R-ring',
  '3-R-ring',
  '5-R-ring',
  '7-R-ring',
  '8-R-ring',
  '9-R-ring',
  '10-R-ring',
  '11-R-ring',
  '12-R-ring',
  '1-L-little',
  '2-L-little',
  '3-L-little',
  '5-L-little',
  '7-L-little',
  '8-L-little',
  '9-L-little',
  '10-L-little',
  '11-L-little',
  '12-L-little',
  '1-R-little',
  '2-R-little',
  '3-R-little',
  '5-R-little',
  '7-R-little',
  '8-R-little',
  '9-R-little',
  '10-R-little',
  '11-R-little',
  '12-R-little'}; %#ok<*COMNL>
l=length(names);

for h=1:1:l
  [X, map] = imread(names{h},'gif');
  [m,n] = size(X);
  white=0;
  lightestpink=0;
  lighterpink=0;
  lightpink=0;
  darkpink=0;
  darkerpink=0;
  darkestpink=0;
  hand=0;
  for i=1:1:m
    for j=1:1:n
      switch X(i,j)
        case 0 % #ffccff (lightest pink)
          lightestpink=lightestpink+1;
          hand=hand+1;
        case 1 % #ff99ff (lighter pink)
          lighterpink=lighterpink+1;
          hand=hand+1;
        case 2 % #ff66ff (light pink)
          lightpink=lightpink+1;
          hand=hand+1;
```

```
        case 3 % #ff33ff (dark pink)
          darkpink=darkpink+1;
          hand=hand+1;
        case 4 % #ff00ff (darker pink)
          darkerpink=darkerpink+1;
          hand=hand+1;
        case 5 % #cc0099 (darkest pink)
          darkestpink=darkestpink+1;
          hand=hand+1;
        case 6 % #ffffff (white)
          white=white+1;
          hand=hand+1;
        otherwise % #000000 (black)
      end
    end
  end
  % get percentages
  amounts(h,1)=lightestpink; %#ok<*SAGROW>
  amounts(h,2)=lighterpink;
  amounts(h,3)=lightpink;
  amounts(h,4)=darkpink;
  amounts(h,5)=darkerpink;
  amounts(h,6)=darkestpink;
  amounts(h,7)=white;
  amounts(h,8)=hand;
  percentages(h,1)=100*lightestpink/hand;
  percentages(h,2)=100*lighterpink/hand;
  percentages(h,3)=100*lightpink/hand;
  percentages(h,4)=100*darkpink/hand;
  percentages(h,5)=100*darkerpink/hand;
  percentages(h,6)=100*darkestpink/hand;
  percentages(h,7)=100*white/hand;

  % apply pressure scaling
  if findstr(names{h}, '1-') || findstr(names{h}, '2-') ||
findstr(names{h}, '3-') || findstr(names{h}, '5-')
    % For subjects 1, 2, 3, & 5:
    % darkest pink -> 0.20 MPa (29 psi)
    % darker pink -> 0.20 MPa (29 psi)
    % dark pink -> 0.20 MPa (29 psi)
    % light pink -> 0.195 MPa (28 psi)
    % lighter pink -> 0.0975 MPa (14 psi)
    % lightest pink -> 0.05 MPa (7 psi)

    % get weighted average of average pressure in region

weightedaverage(h)=(percentages(h,6)*0.20+percentages(h,5)*0.20+percentages
(h,4)*0.20+percentages(h,3)*0.195+percentages(h,2)*0.0975+percentages(h,1)*
0.05+percentages(h,7)*0)/100;

    fprintf('%s %f group 1\n',names{h},weightedaverage(h))
  else
    % For subjects 7-12:
    % darkest pink -> 0.20 MPa (29 psi)
    % darker pink -> 0.1925 MPa (28 psi)
    % dark pink -> 0.1575 MPa (23 pso)
    % light pink -> 0.13 MPa (19 psi)
    % lighter pink -> 0.0875 MPa (13 psi)
```

```
    % lightest pink -> 0.05 MPa (7 psi)

    % get weighted average of average pressure in region

weightedaverage(h)=(percentages(h,6)*0.20+percentages(h,5)*0.1925+percentag
es(h,4)*0.1575+percentages(h,3)*0.13+percentages(h,2)*0.0875+percentages(h,
1)*0.05+percentages(h,7)*0)/100;

    fprintf('%s %f group 2\n',names{h},weightedaverage(h))
  end


end
```

A.3: MATLAB scripts for statistical evaluation.

```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Traction Only Plots\n\n')

% read in Excel files
names={'subject01trial01tractiononly',
  'subject01trial02tractiononly',
  'subject02trial01tractiononly',
  'subject02trial02tractiononly',
  'subject02trial03tractiononly',
  'subject03trial01tractiononly',
  'subject03trial02tractiononly',
  'subject03trial03tractiononly',
  'subject05trial01tractiononly',
  'subject05trial02tractiononly',
  'subject05trial03tractiononly',
  'subject07trial01tractiononly',
  'subject07trial02tractiononly',
  'subject07trial03tractiononly',
  'subject08trial01tractiononly',
  'subject08trial02tractiononly',
  'subject08trial03tractiononly',
  'subject09trial01tractiononly',
  'subject09trial02tractiononly',
  'subject09trial03tractiononly',
  'subject10trial01tractiononly',
  'subject10trial02tractiononly',
  'subject10trial03tractiononly',
  'subject11trial01tractiononly',
  'subject11trial02tractiononly',
  'subject11trial03tractiononly',
  'subject11trial04tractiononly',
  'subject12trial01tractiononly',
  'subject12trial02tractiononly',
  'subject12trial03tractiononly'};
l=length(names);
% Subject 1 only did two sets of this trial.
% Subject 11 did four sets of this trial.
% Everyone else did the standard three sets.

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+13),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+13),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+13),:))));
```

```
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Left Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+36),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+36),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+36),:))));
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Right Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
end
```

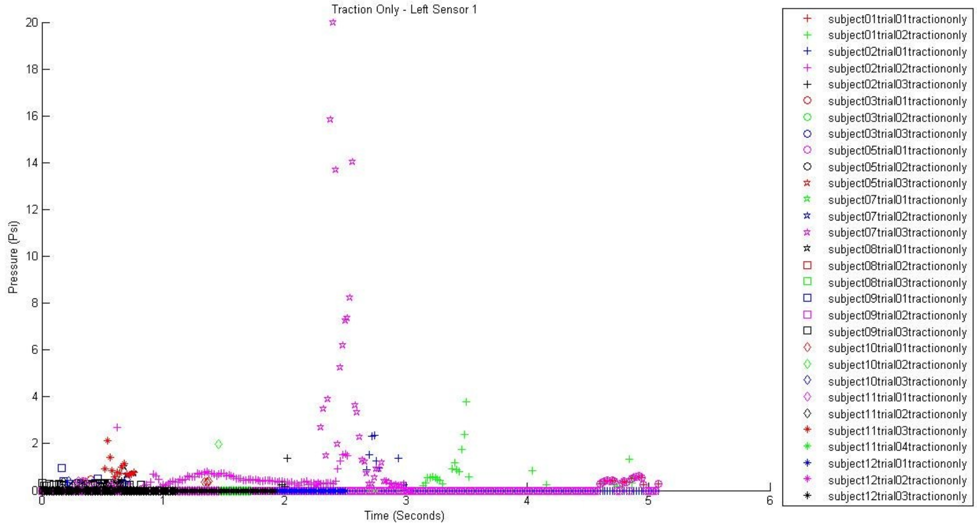
```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Bad Run Statistics\n\n')

% read in Excel files
names={'subject01trialbad',
  'subject02trialbad',
  'subject03trialbad',
  'subject05trialbad',
  'subject07trialbad',
  'subject08trialbad',
  'subject09trialbad',
  'subject10trialbad',
  'subject11trialbad',
  'subject12trialbad'};
l=length(names);

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+13),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+13),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+13),:))));
```

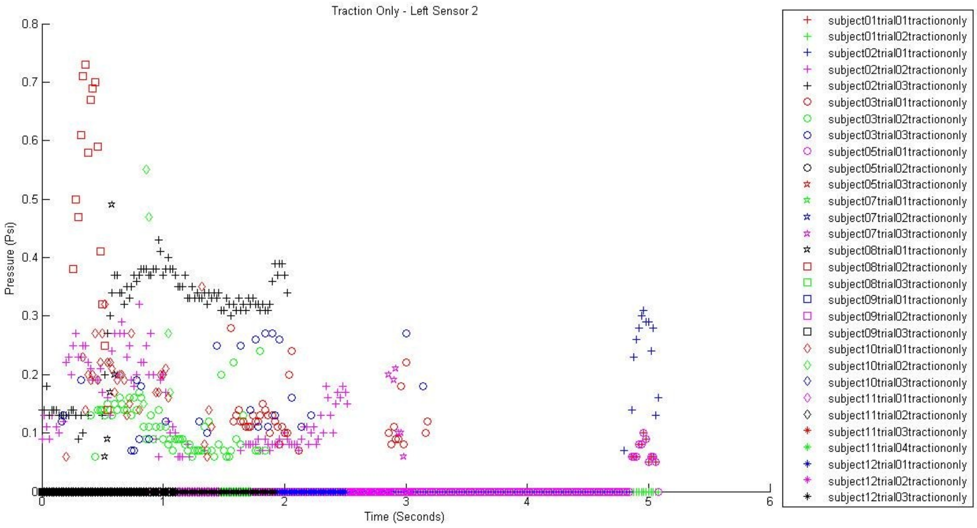
```
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Left Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+36),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+36),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+36),:))));
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Right Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
end
```

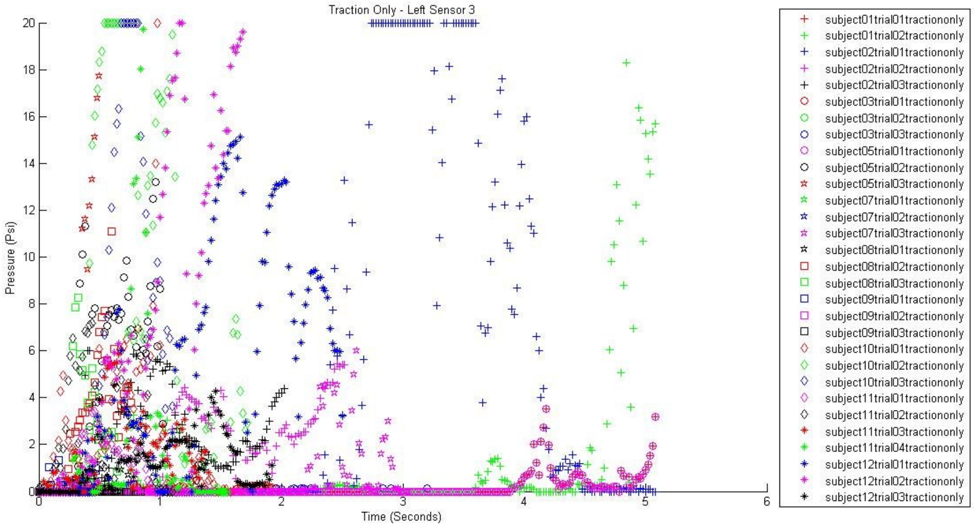
```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Full Delivery Statistics\n\n')

% read in Excel files
names={'subject01trial01fulldelivery',
  'subject01trial02fulldelivery',
  'subject01trial03fulldelivery',
  'subject02trial01fulldelivery',
  'subject02trial02fulldelivery',
  'subject02trial03fulldelivery',
  'subject03trial01fulldelivery',
  'subject03trial02fulldelivery',
  'subject03trial03fulldelivery',
  'subject07trial01fulldelivery',
  'subject07trial02fulldelivery',
  'subject07trial03fulldelivery',
  'subject08trial01fulldelivery',
  'subject08trial02fulldelivery',
  'subject08trial03fulldelivery',
  'subject09trial01fulldelivery',
  'subject09trial02fulldelivery',
  'subject09trial03fulldelivery',
  'subject10trial01fulldelivery',
  'subject10trial02fulldelivery',
  'subject10trial03fulldelivery',
  'subject11trial01fulldelivery',
```

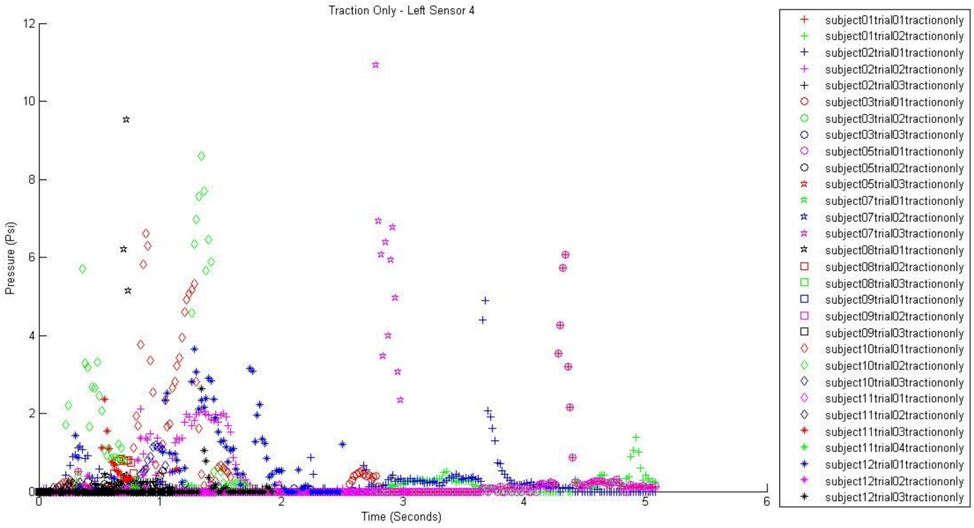
```
  'subject11trial02fulldelivery',
  'subject11trial03fulldelivery',
  'subject12trial01fulldelivery',
  'subject12trial02fulldelivery',
  'subject12trial03fulldelivery'};
l=length(names);

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+13),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+13),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+13),:))));
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Left Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
  for i=1:1:12 % each hand has 12 sensor values
    max_S(h,i)=max(S((i+36),:));
    if max_S(h,i)>0
        mean_nonzero_S(h,i)=mean(nonzeros((S((i+36),:))));
        std_nonzero_S(h,i)=std(nonzeros((S((i+36),:))));
    else
      mean_nonzero_S(h,i)=NaN;
      std_nonzero_S(h,i)=NaN;
    end
    fprintf('%s|Right Sensor %g|Nonzero Mean (Psi)|%f|Nonzero STD
(Psi)|%f|Max (Psi)|%f\n',names{h}, i, mean_nonzero_S(h,i),
std_nonzero_S(h,i), max_S(h,i))
  end
end
```

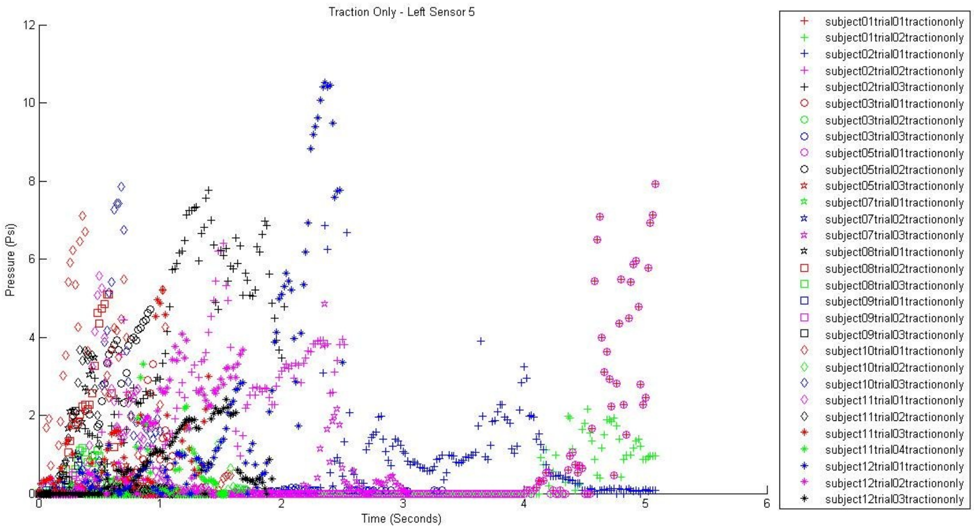
A.4: Sample MATLAB plots of pressure versus time.

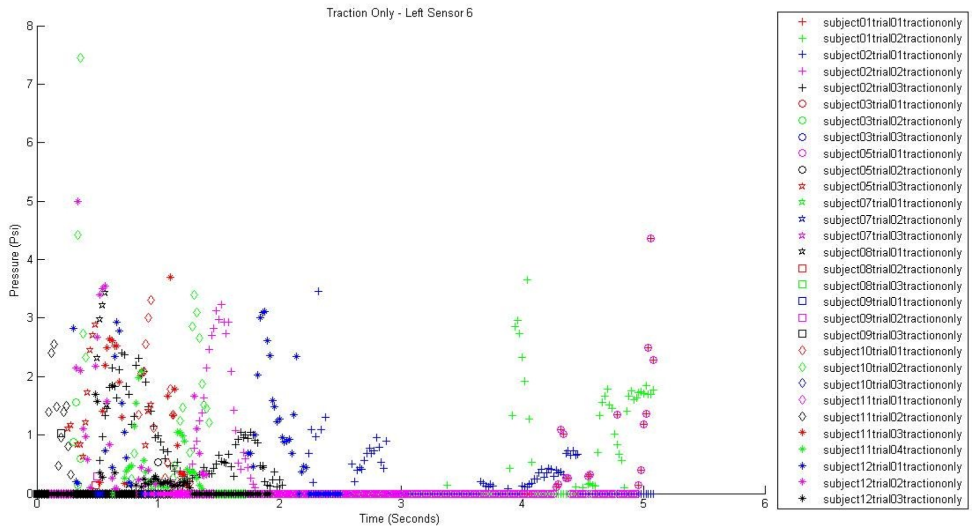


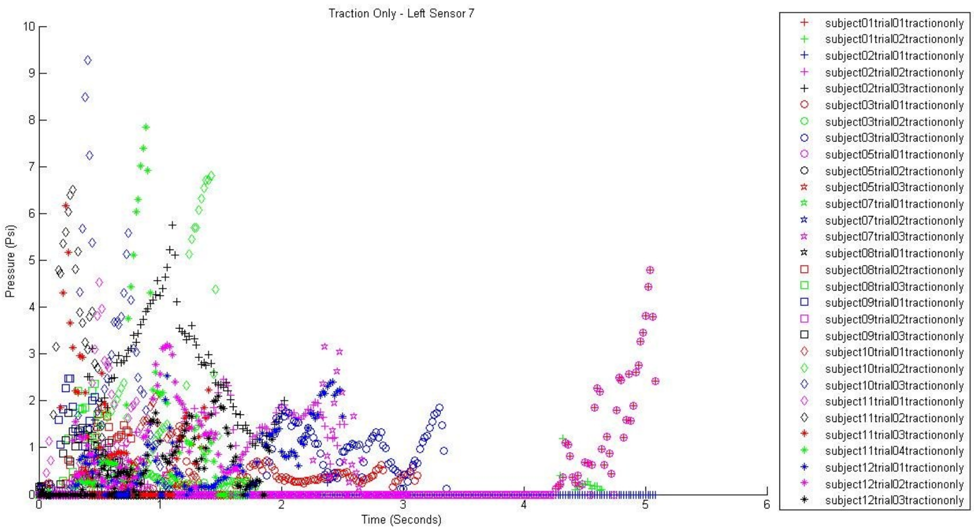


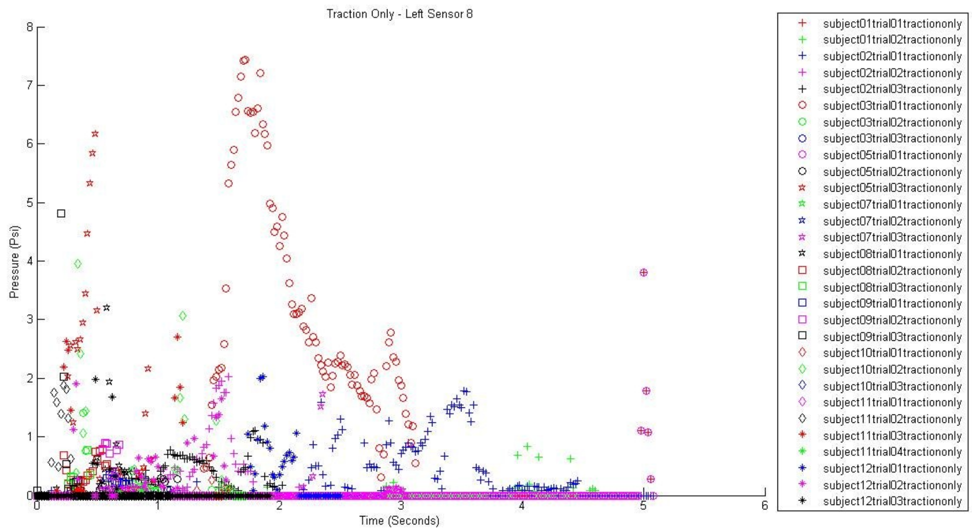

Traction Only - Left Sensor 3
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

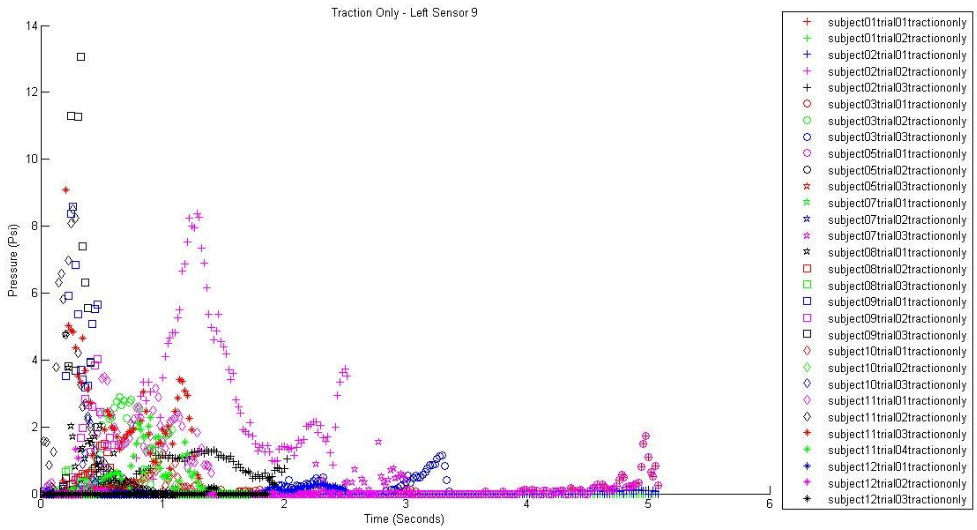

Traction Only - Left Sensor 4
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

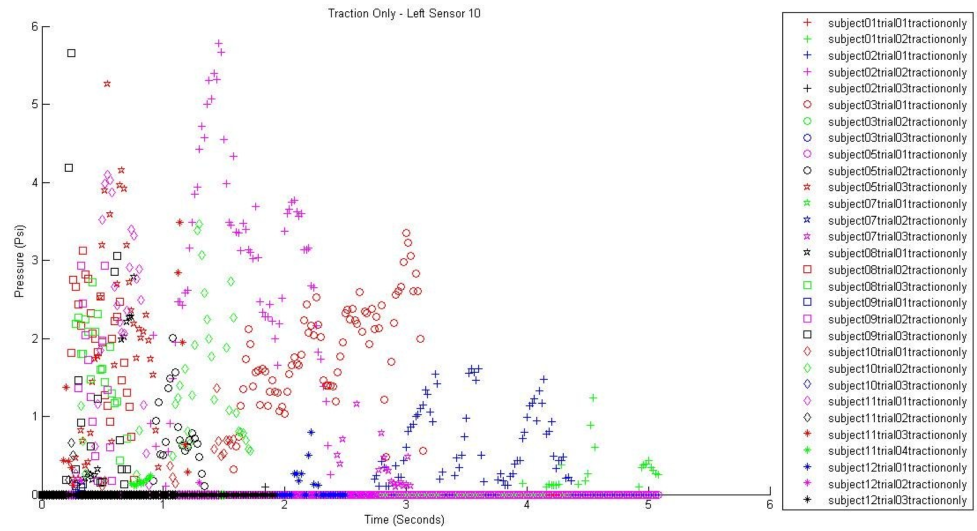

Traction Only - Left Sensor 5
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

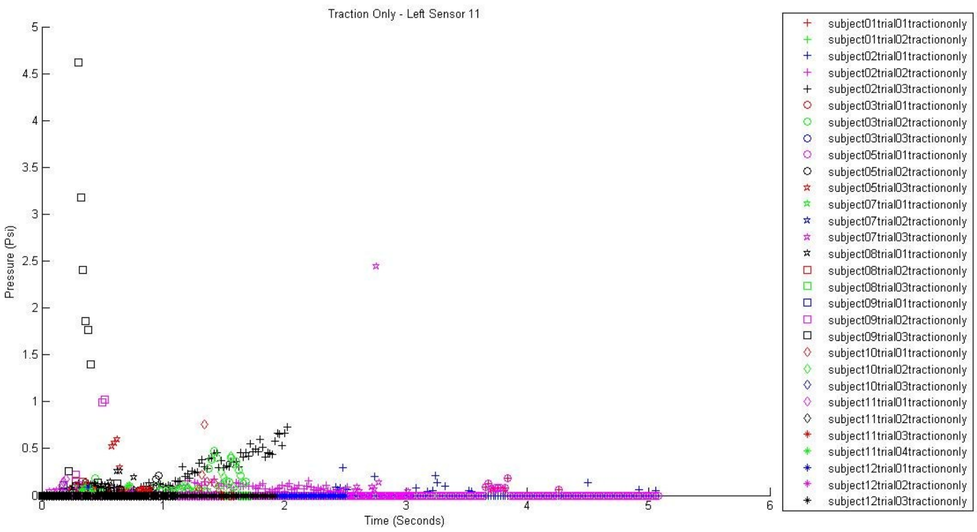

Traction Only - Left Sensor 6
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

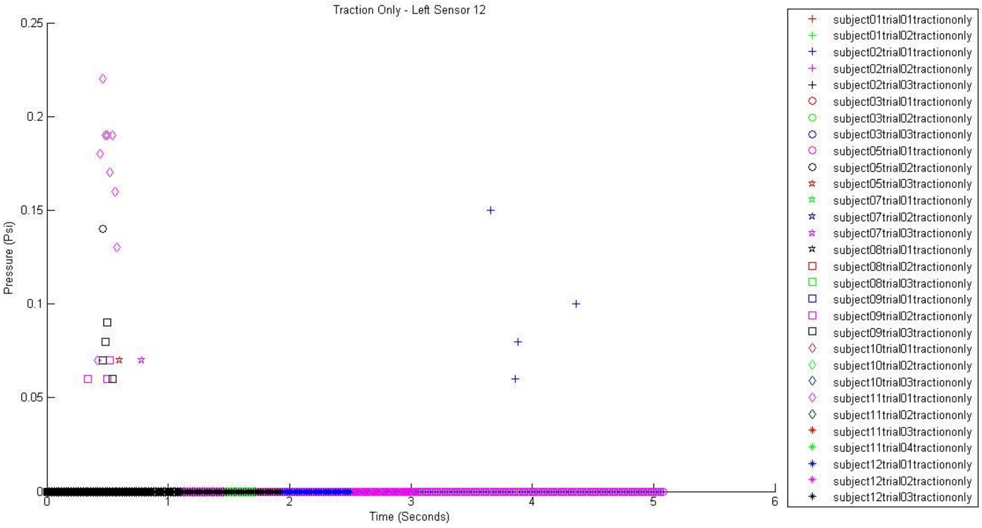

Traction Only - Left Sensor 7
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

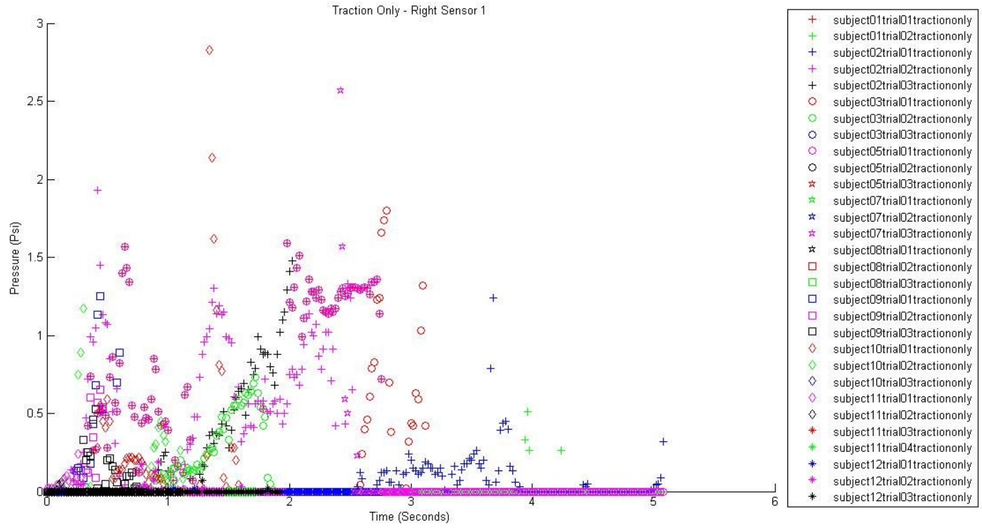

Traction Only - Left Sensor 8
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

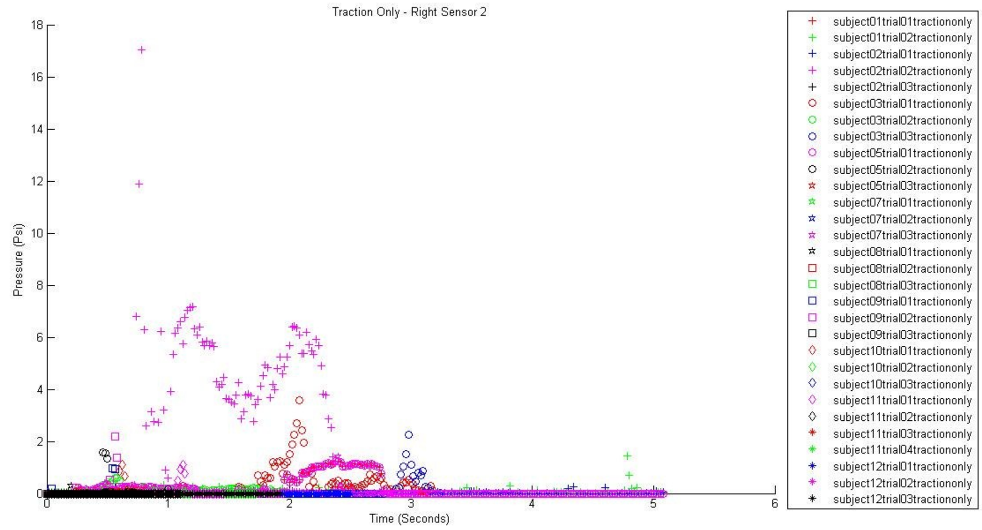

Traction Only - Left Sensor 9
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

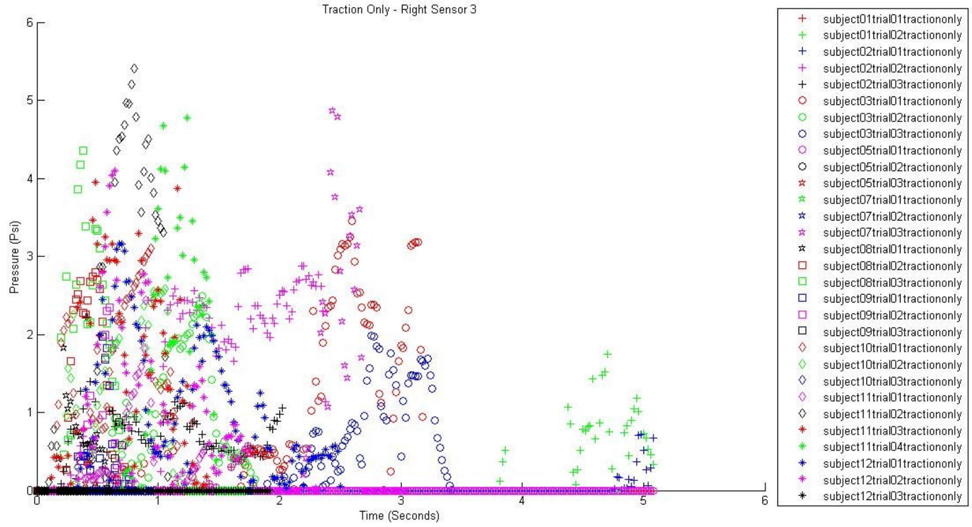

Traction Only - Left Sensor 10
Pressure (Psi)
Time (Seconds)

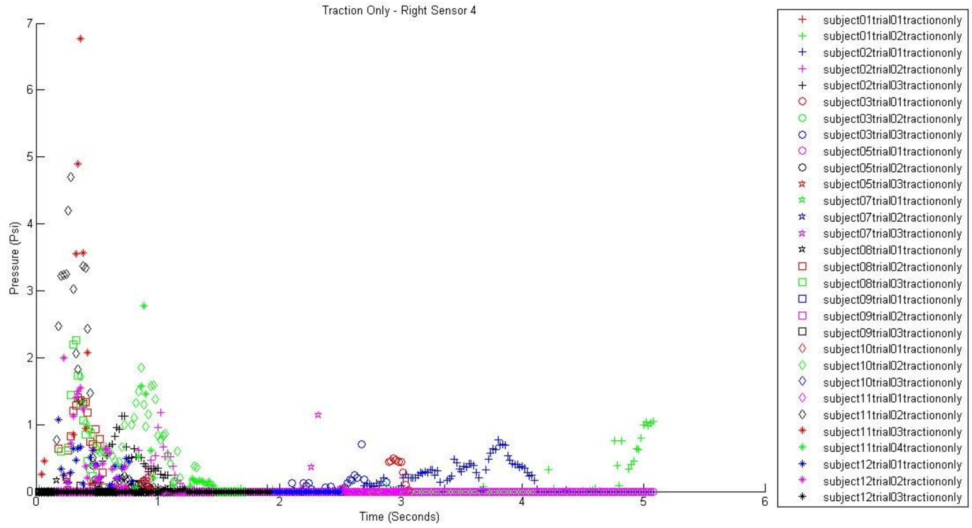

Traction Only - Left Sensor 11
Pressure (Psi)
Time (Seconds)


Traction Only - Left Sensor 12
Pressure (Psi)
Time (Seconds)
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 1
Pressure (Psi)
Time (Seconds)
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 2
Pressure (Psi)
Time (Seconds)
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 3
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 4
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
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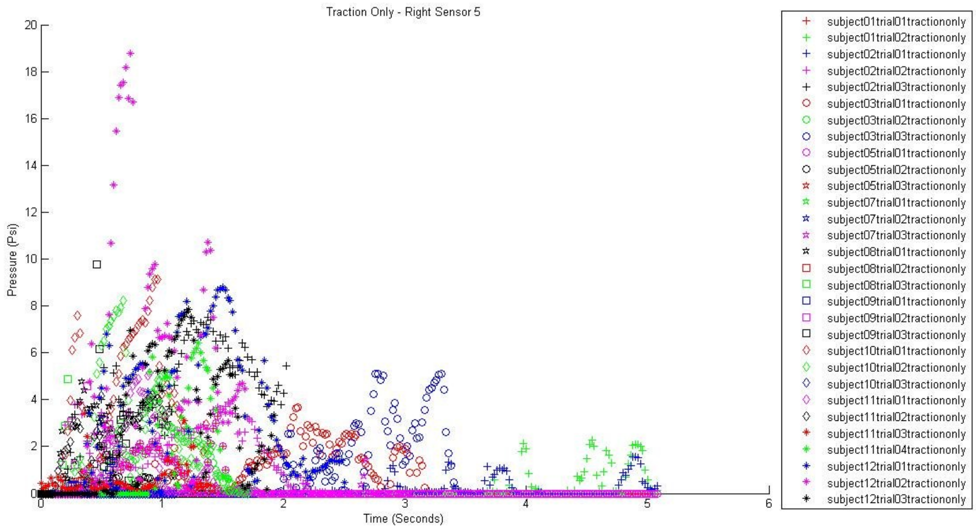
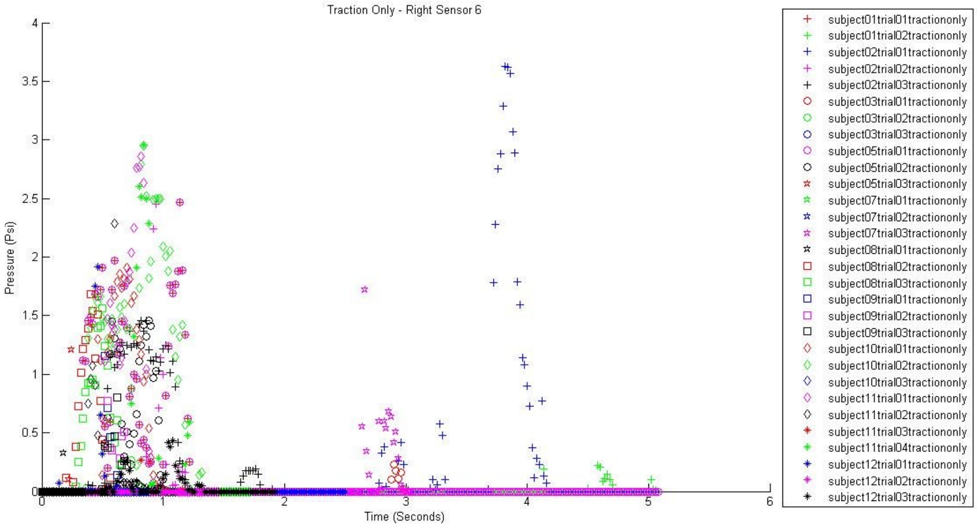
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 5
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
subject08trial02tractiononly
subject08trial03tractiononly
subject09trial01tractiononly
subject09trial02tractiononly
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly



Traction Only - Right Sensor 6
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
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subject09trial01tractiononly
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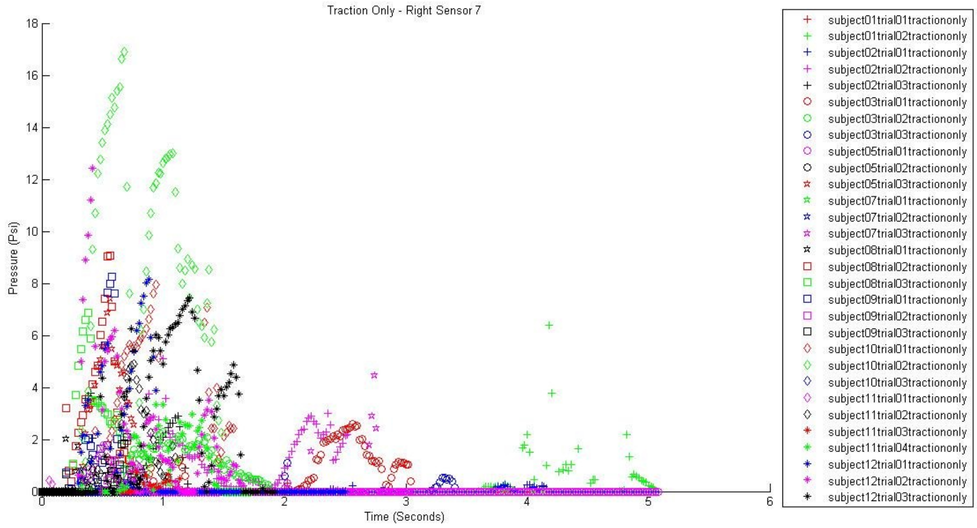
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly



Traction Only - Right Sensor 7
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
subject08trial01tractiononly
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subject09trial01tractiononly
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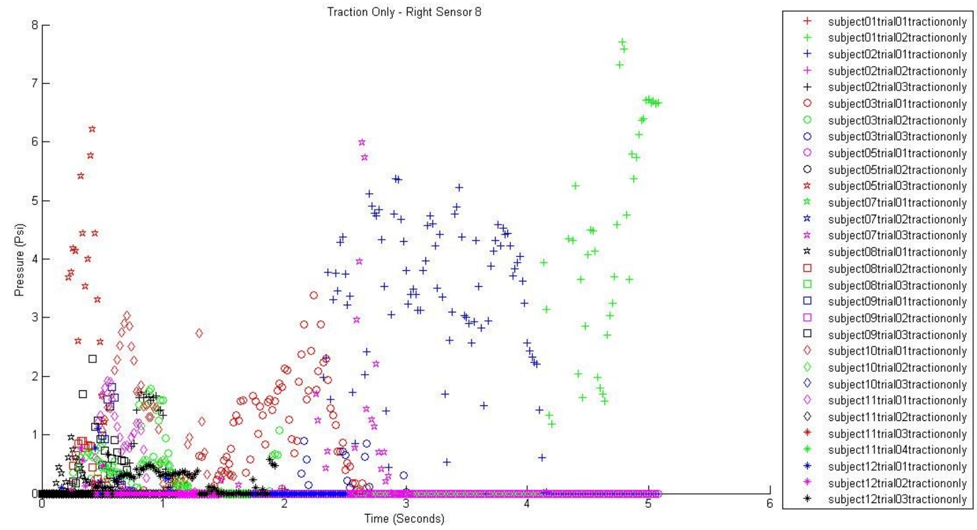
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly



Traction Only - Right Sensor 8
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
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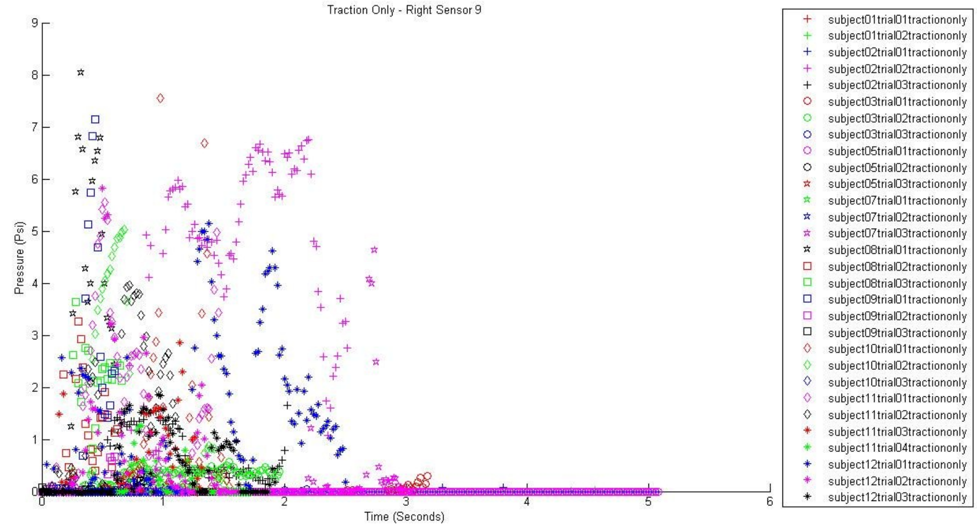
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 9
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
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subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
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subject11trial04tractiononly
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subject12trial02tractiononly
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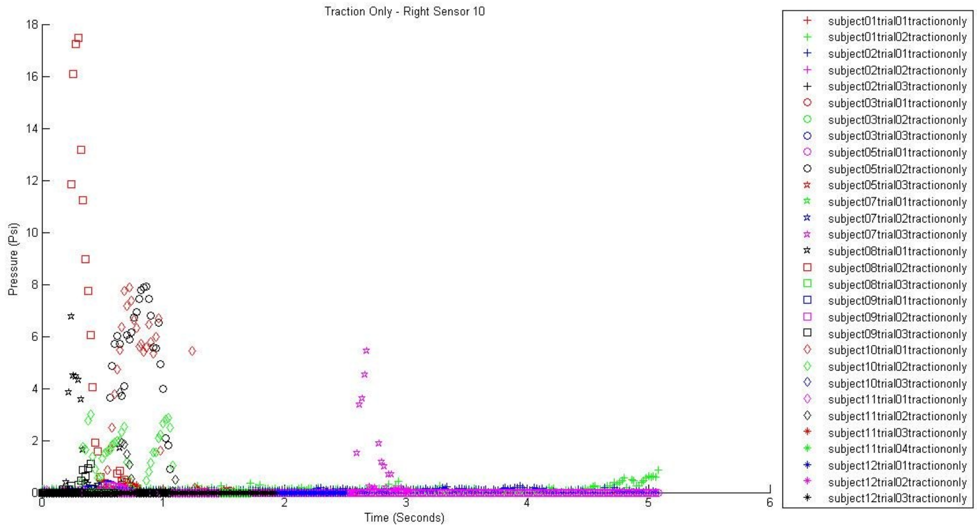
Traction Only - Right Sensor 10
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
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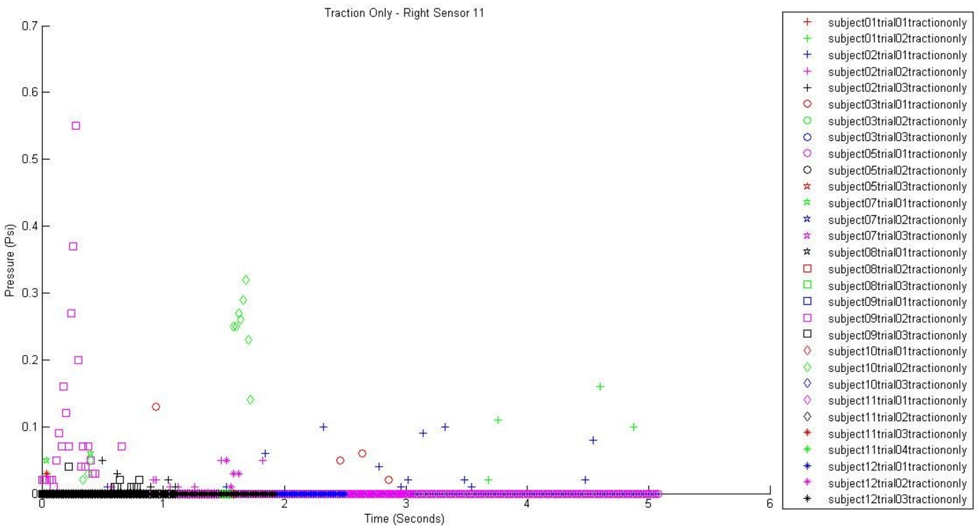
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 11
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
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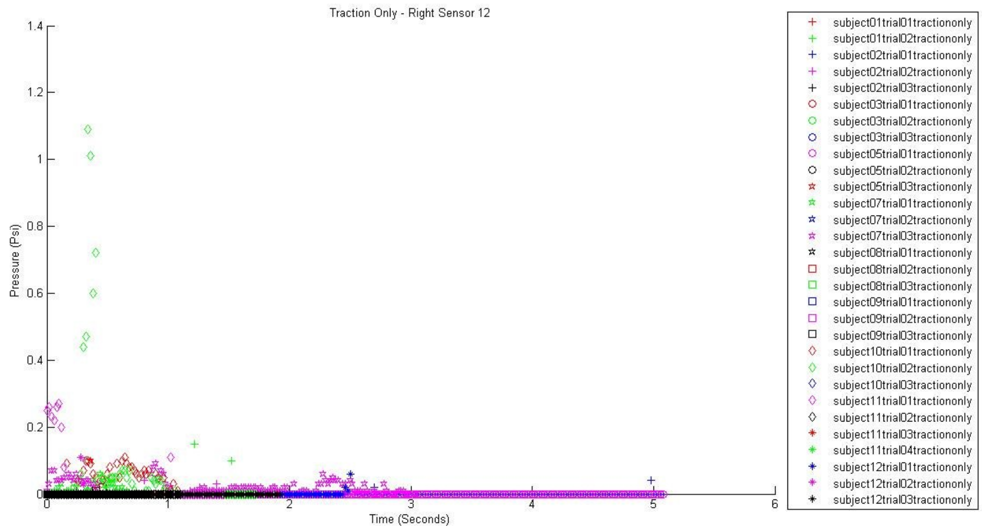
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly


Traction Only - Right Sensor 12
Pressure (Psi)
Time (Seconds)
subject01trial01tractiononly
subject01trial02tractiononly
subject02trial01tractiononly
subject02trial02tractiononly
subject02trial03tractiononly
subject03trial01tractiononly
subject03trial02tractiononly
subject03trial03tractiononly
subject05trial01tractiononly
subject05trial02tractiononly
subject05trial03tractiononly
subject07trial01tractiononly
subject07trial02tractiononly
subject07trial03tractiononly
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subject09trial01tractiononly
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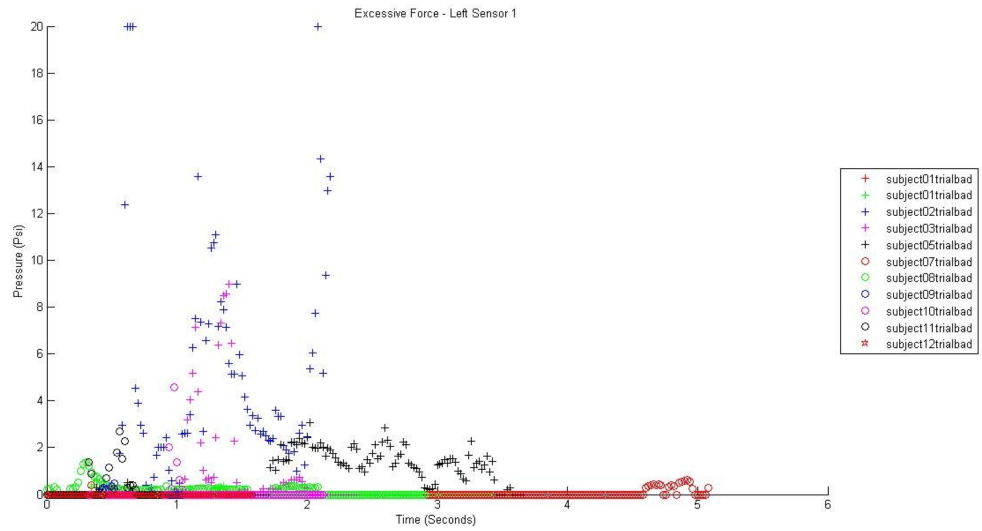
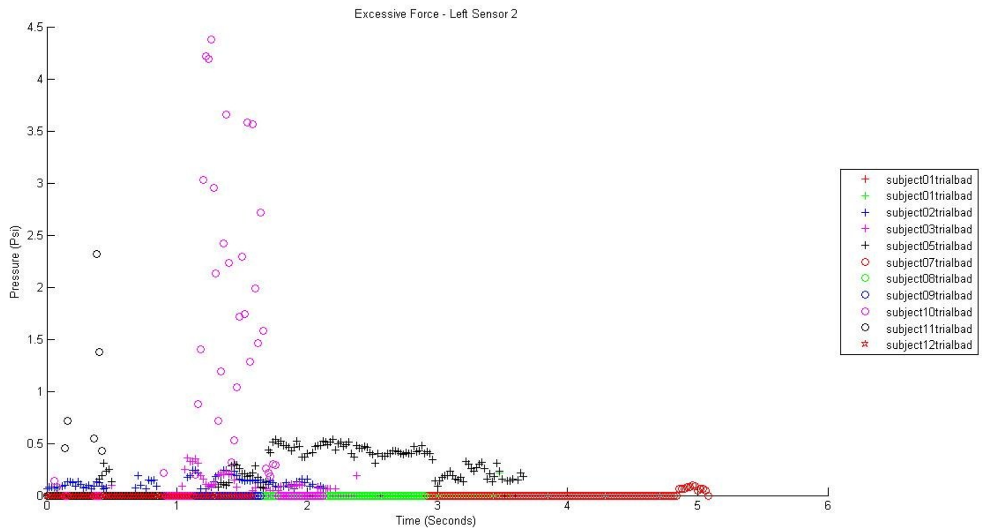
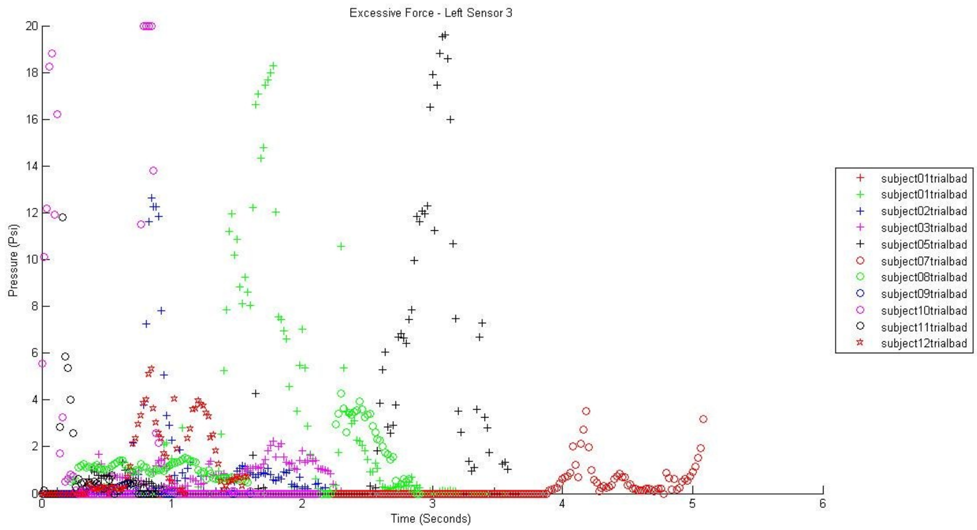
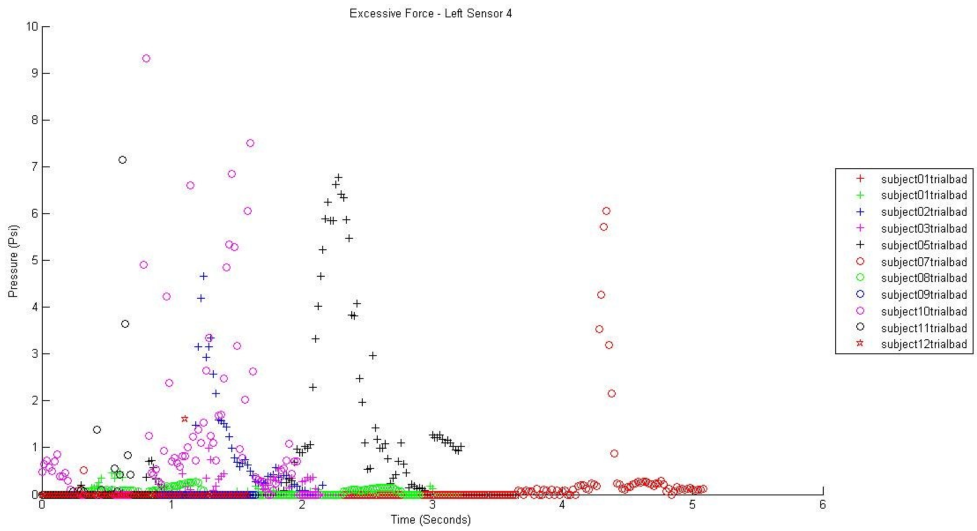
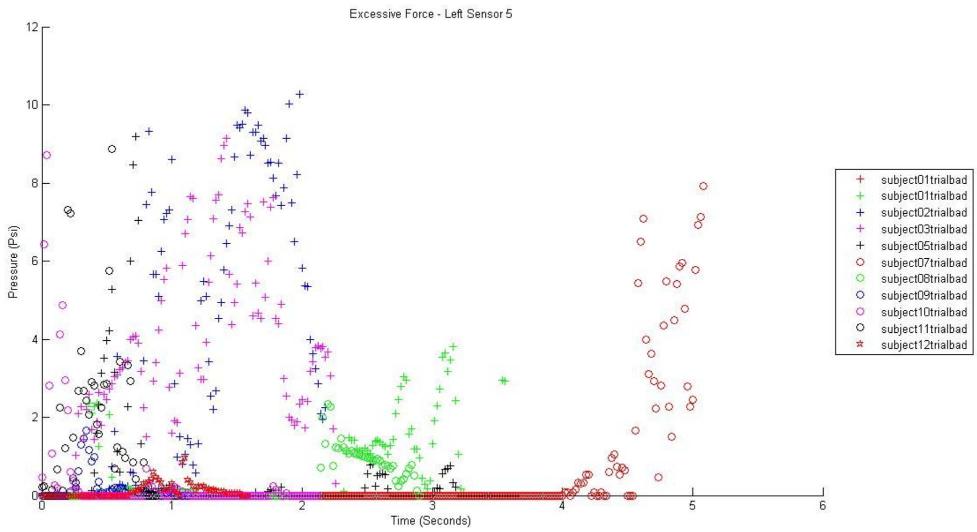
subject09trial03tractiononly
subject10trial01tractiononly
subject10trial02tractiononly
subject10trial03tractiononly
subject11trial01tractiononly
subject11trial02tractiononly
subject11trial03tractiononly
subject11trial04tractiononly
subject12trial01tractiononly
subject12trial02tractiononly
subject12trial03tractiononly

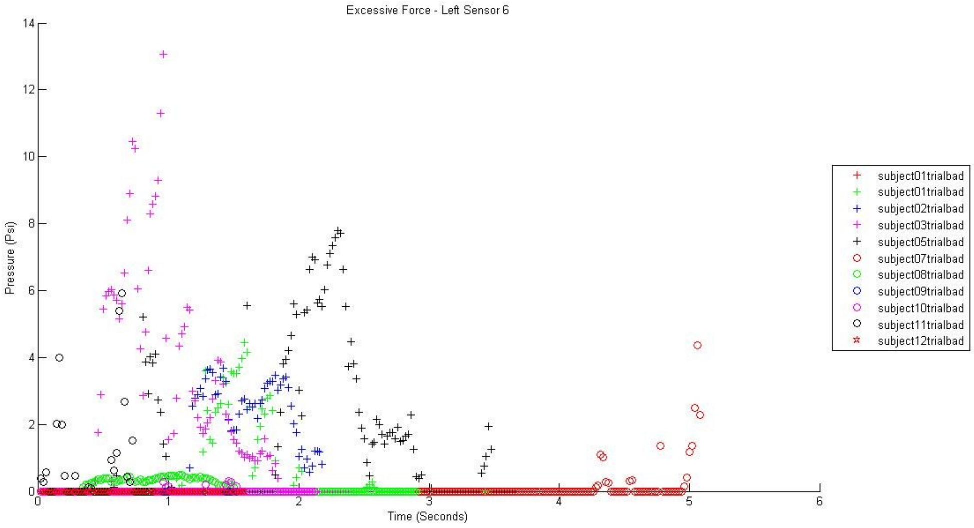

Excessive Force - Left Sensor 1
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

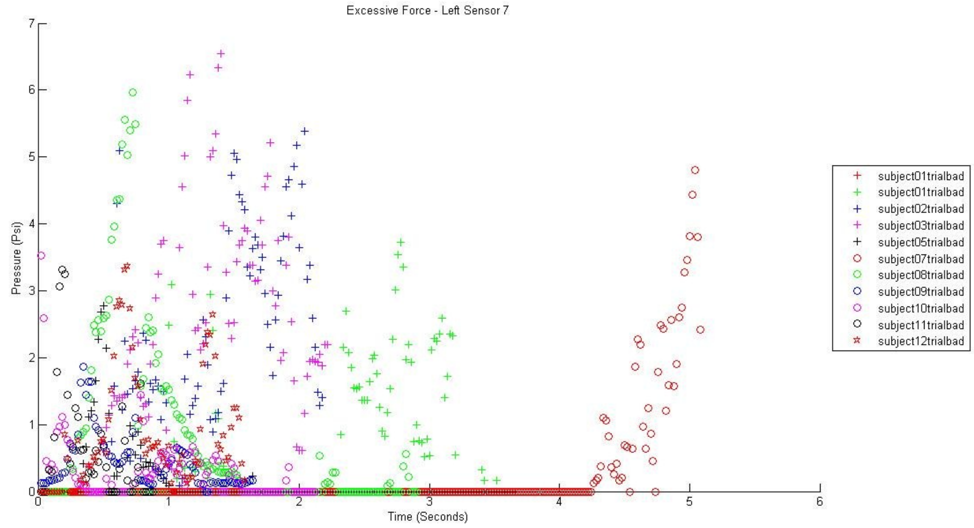

Excessive Force - Left Sensor 2
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

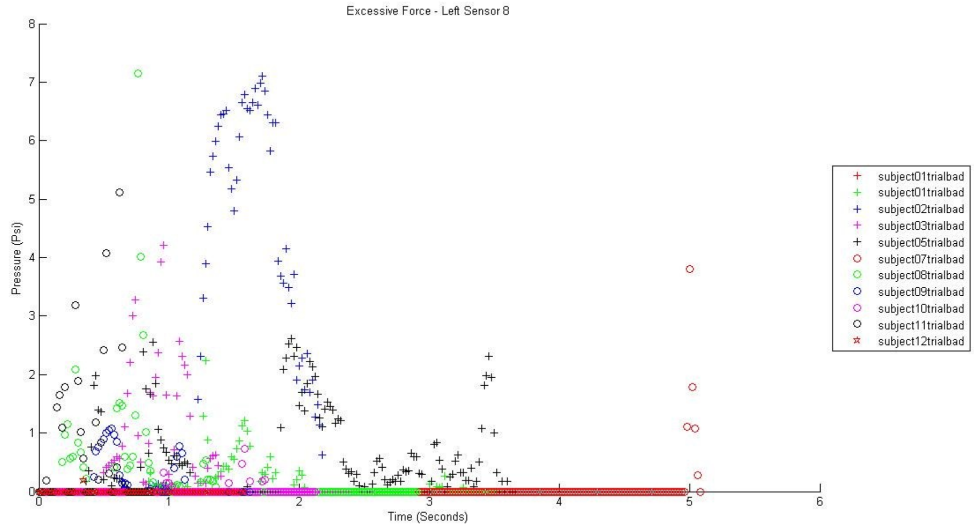

Excessive Force - Left Sensor 3
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

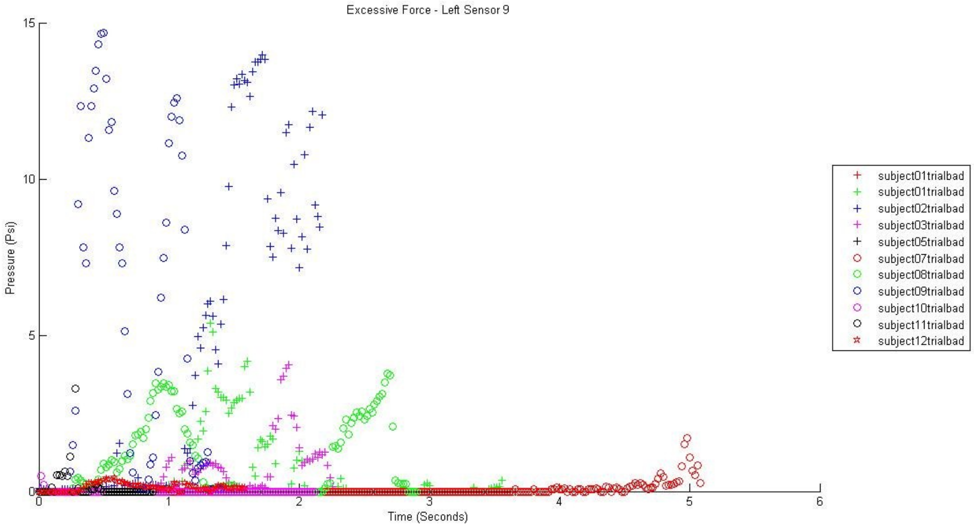

Excessive Force - Left Sensor 4
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

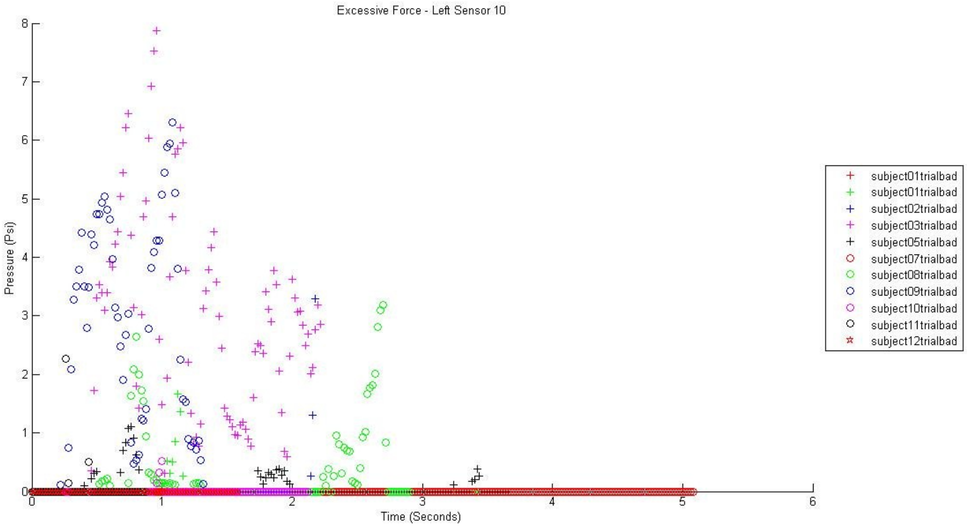

Excessive Force - Left Sensor 5
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

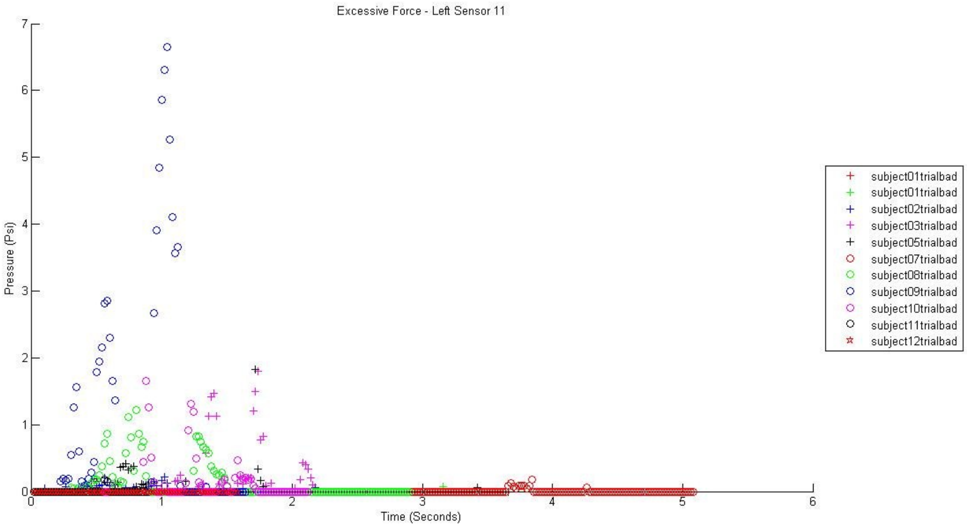

Excessive Force - Left Sensor 6
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad

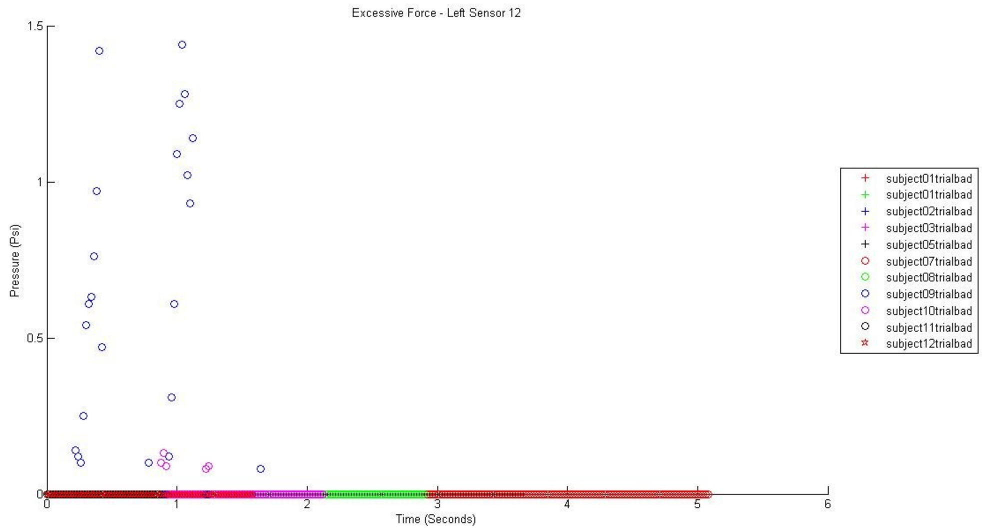

Excessive Force - Left Sensor 7
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Left Sensor 8
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Left Sensor 9
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Left Sensor 10
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Left Sensor 11
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Left Sensor 12
Pressure (Psi)
Time (Seconds)
0
0.5
1
1.5
1
2
3
4
5
6
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
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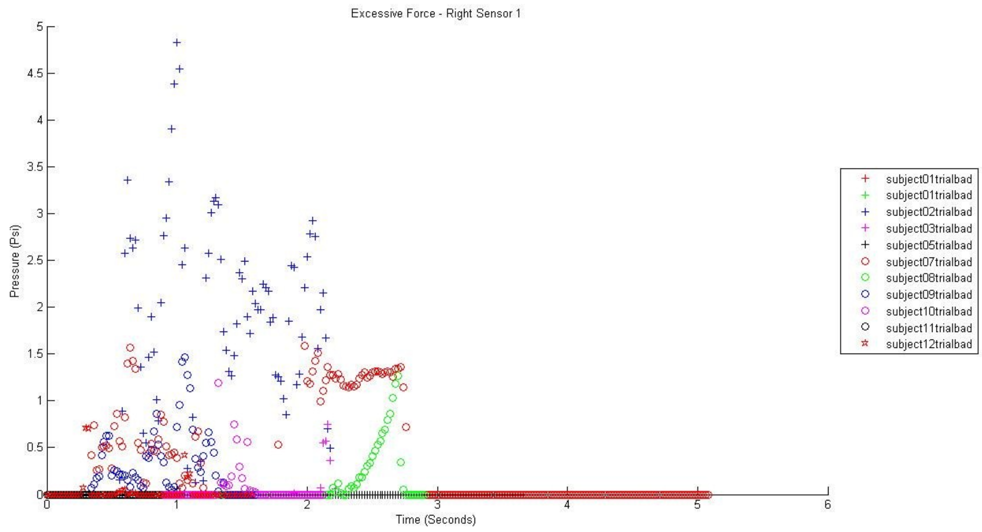
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 1
Pressure (Psi)
Time (Seconds)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1
2
3
4
5
6
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
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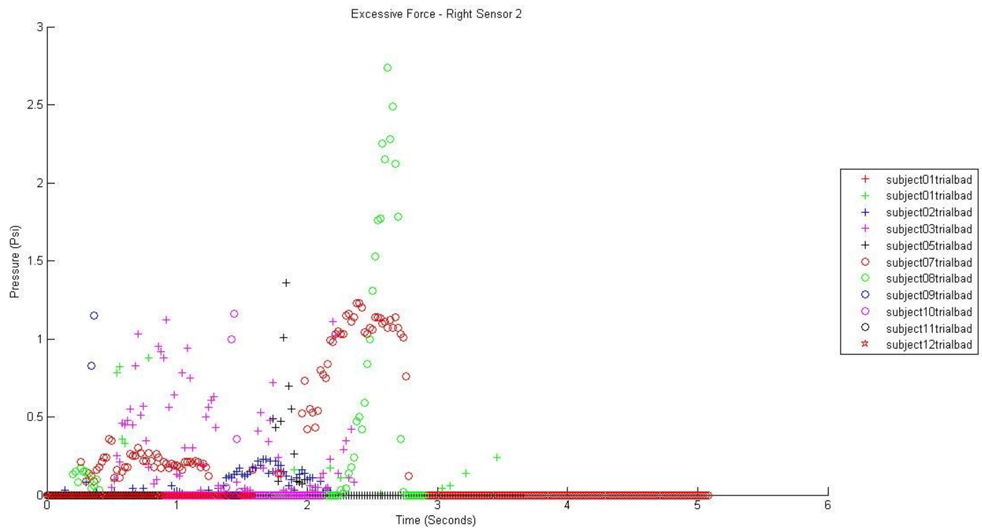
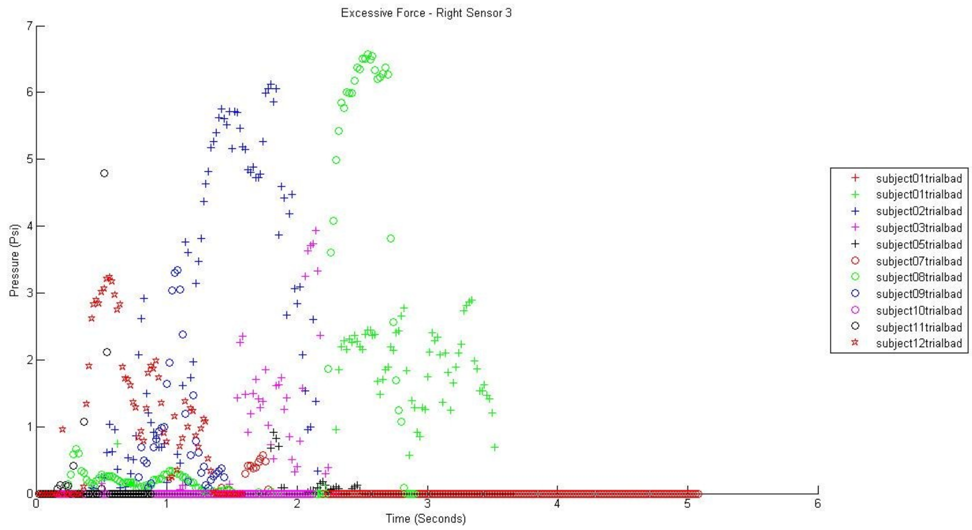
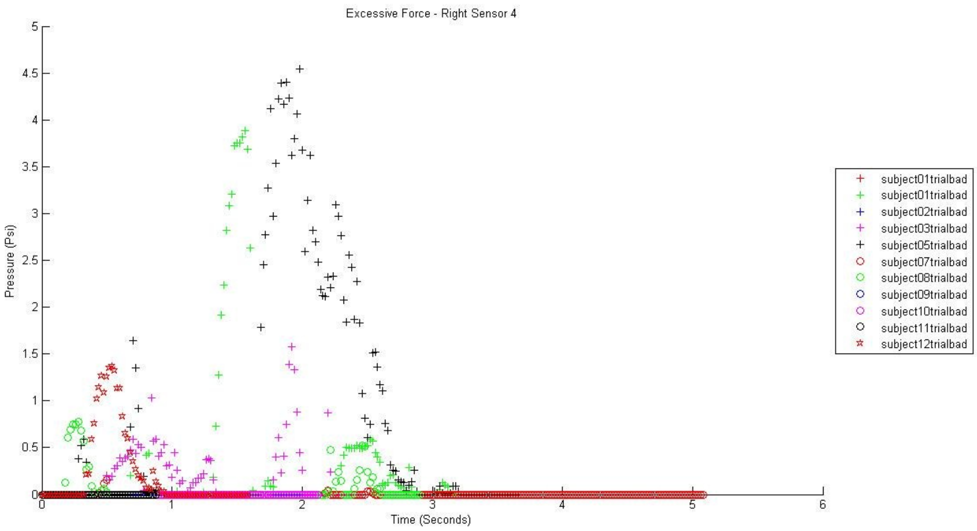
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 2
Pressure (Psi)
Time (Seconds)
0
0.5
1
1.5
2
2.5
3
1
2
3
4
5
6
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 3
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 4
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
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subject09trialbad
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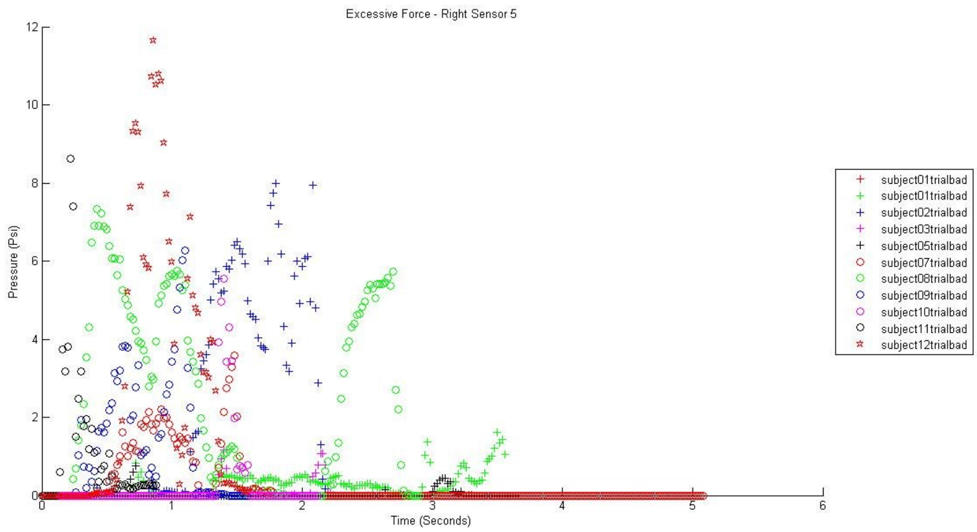
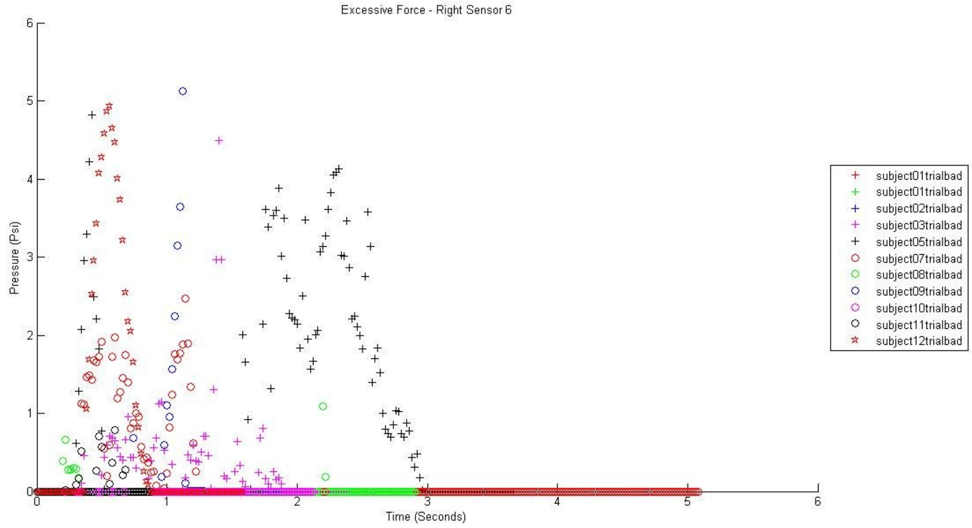
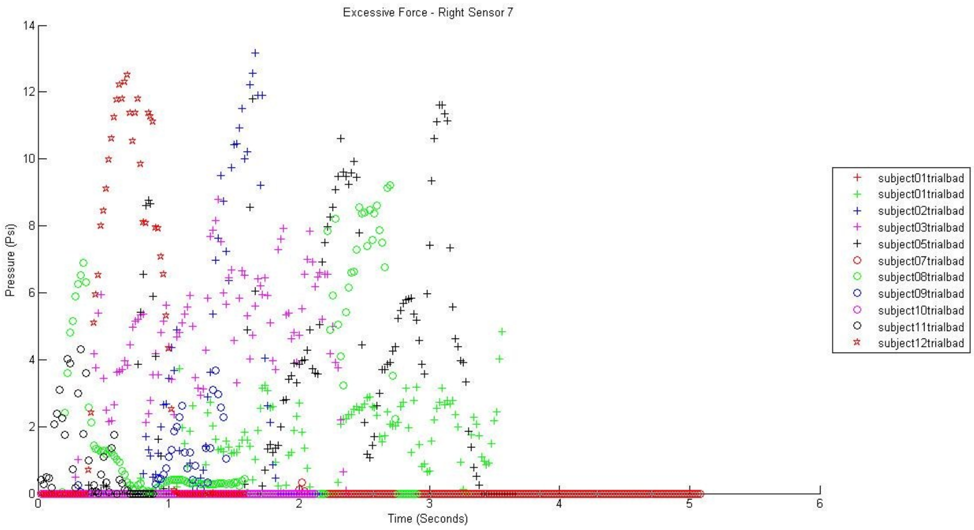
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 5
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 6
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 7
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
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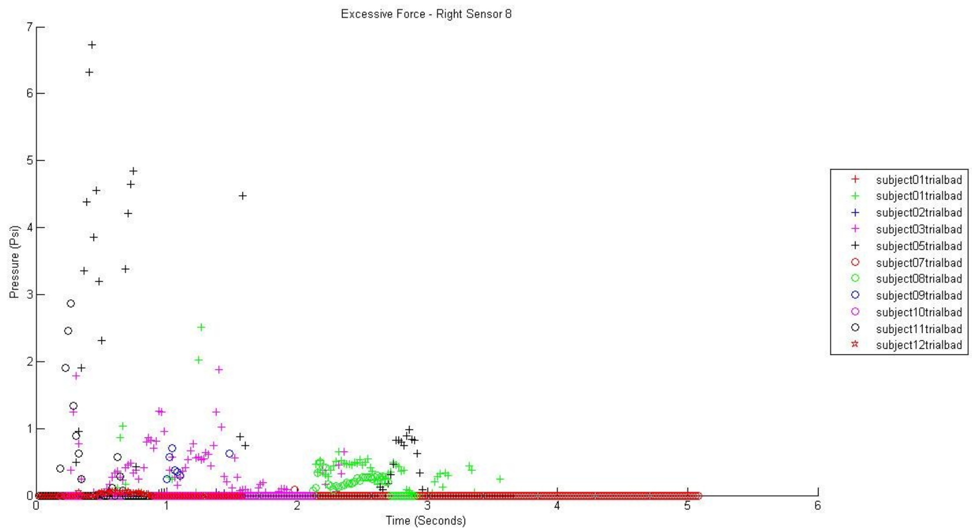
Excessive Force - Right Sensor 8
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
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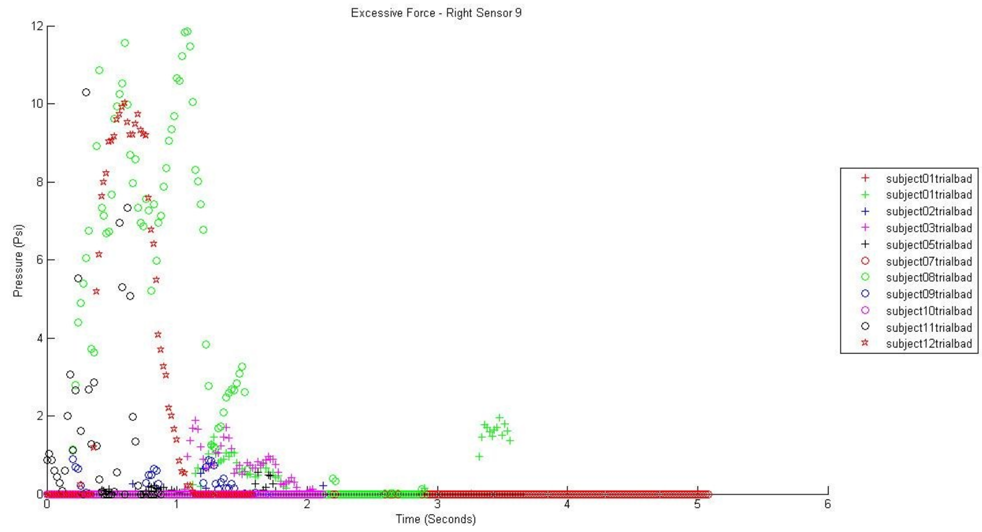
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 9
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
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subject09trialbad
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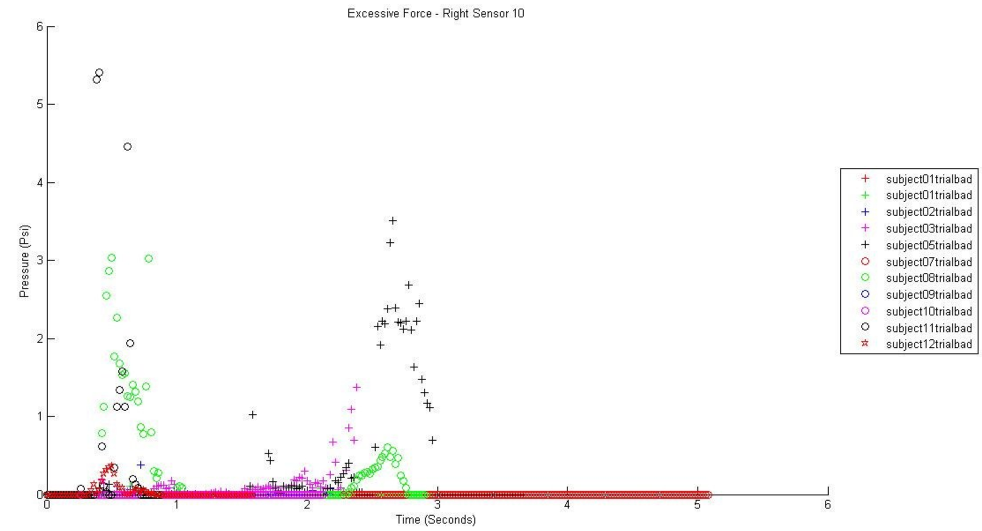
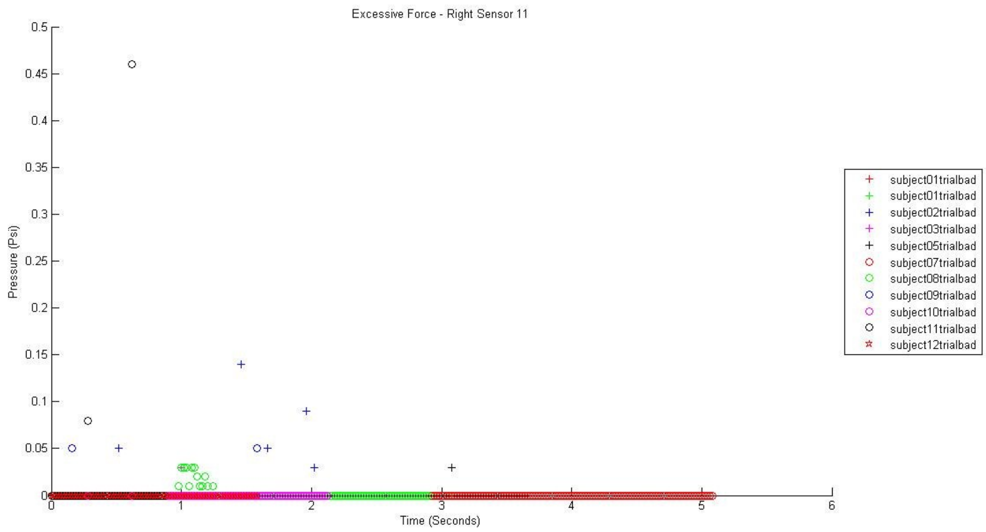
subject12trialbad


Excessive Force - Right Sensor 10
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
subject02trialbad
subject03trialbad
subject05trialbad
subject07trialbad
subject08trialbad
subject09trialbad
subject10trialbad
subject11trialbad
subject12trialbad


Excessive Force - Right Sensor 11
Pressure (Psi)
Time (Seconds)
subject01trialbad
subject01trialbad
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subject03trialbad
subject05trialbad
subject07trialbad
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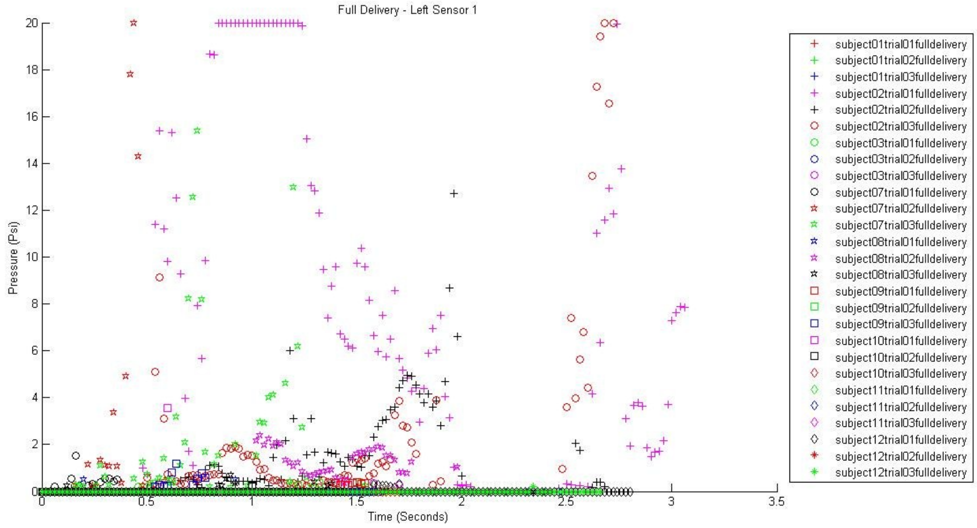
subject11trialbad
subject12trialbad


Full Delivery - Left Sensor 1
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
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subject02trial03fulldelivery
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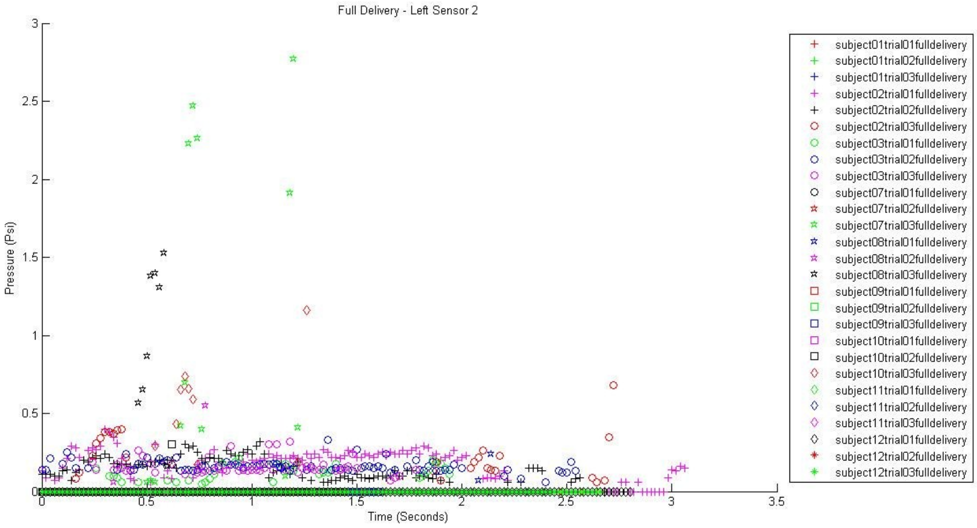
Full Delivery - Left Sensor 2
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
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subject10trial03fulldelivery
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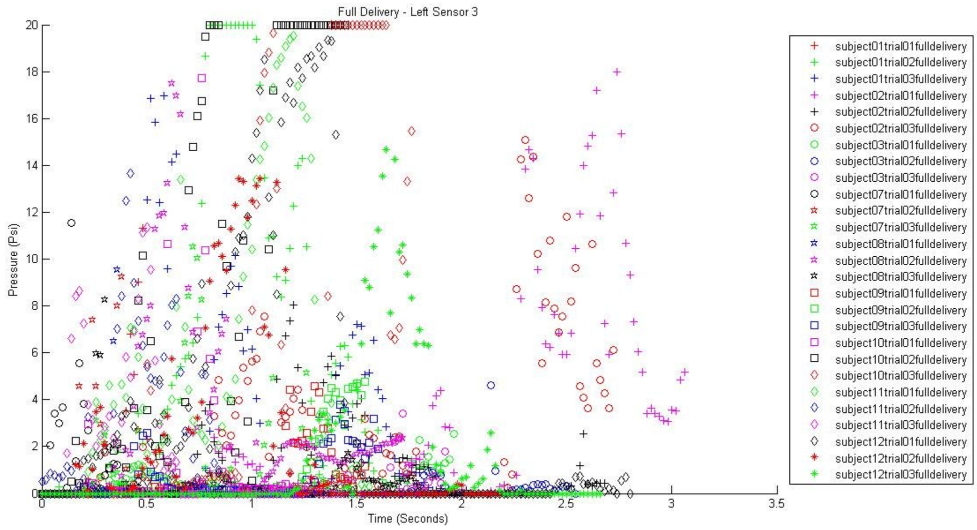
Full Delivery - Left Sensor 3
Pressure (Psi)
Time (Seconds)
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subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
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subject10trial03fulldelivery
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subject12trial02fulldelivery
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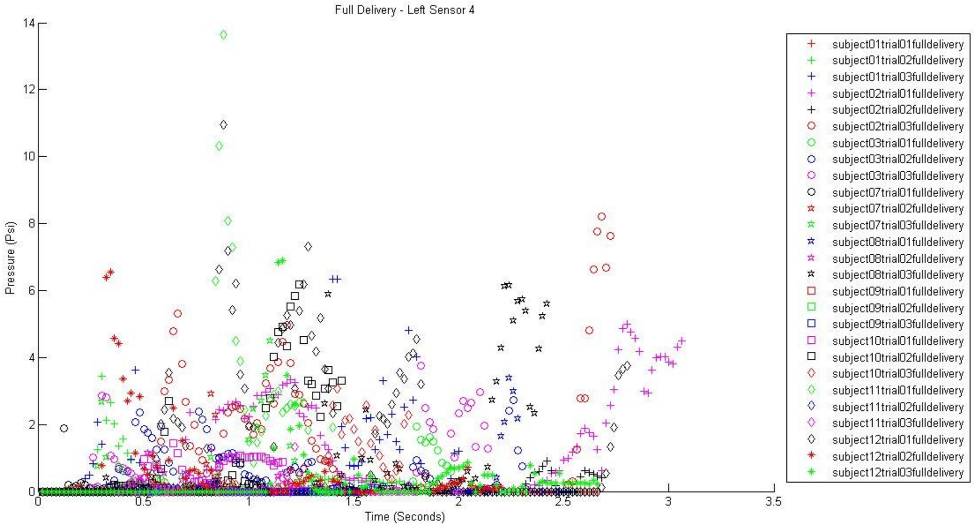
Full Delivery - Left Sensor 4
Pressure (Psi)
Time (Seconds)
0
2
4
6
8
10
12
14
0.5
1
1.5
2
2.5
3
3.5
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
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subject02trial02fulldelivery
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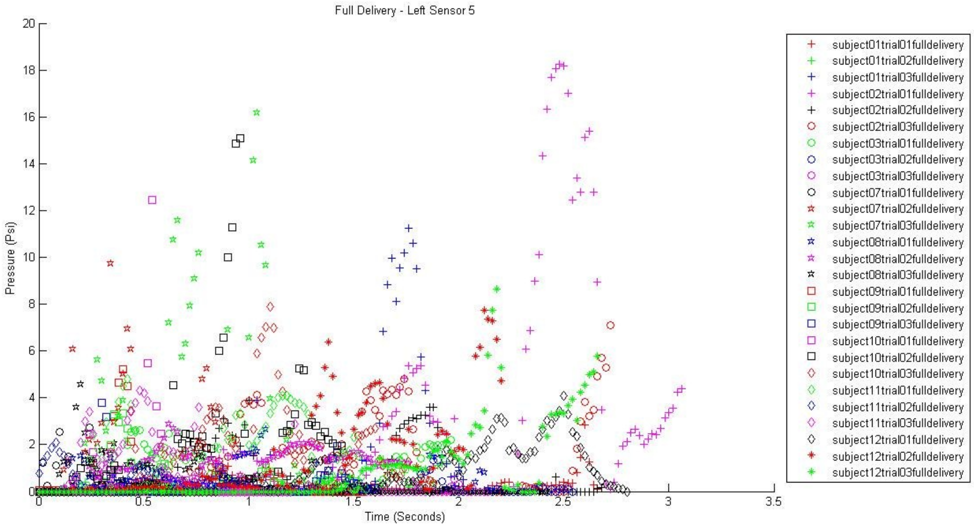
Full Delivery - Left Sensor 5
Pressure (Psi)
Time (Seconds)
0
2
4
6
8
10
12
14
16
18
20
0.5
1
1.5
2
2.5
3
3.5
subject01trial01fulldelivery
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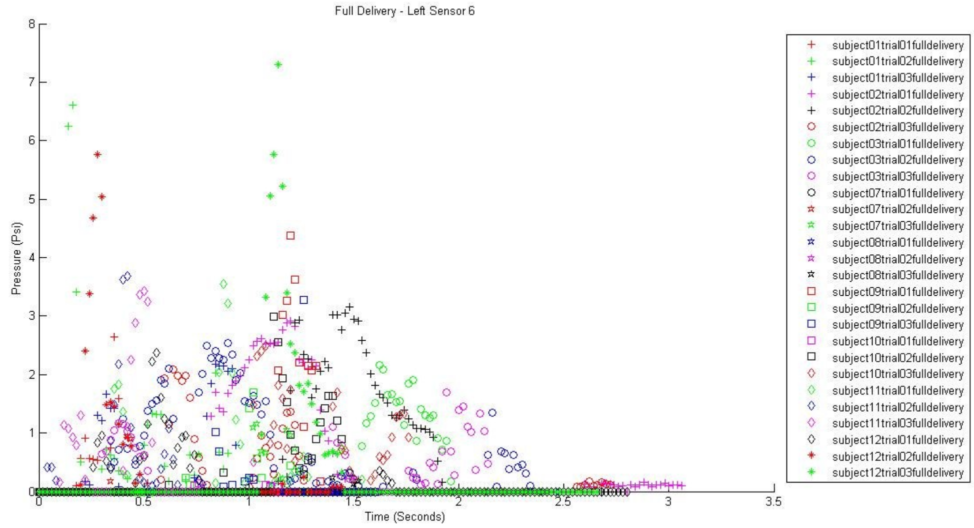
Full Delivery - Left Sensor 6
Pressure (Psi)
Time (Seconds)
0
1
2
3
4
5
6
7
8
0.5
1
1.5
2
2.5
3
3.5
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
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subject03trial01fulldelivery
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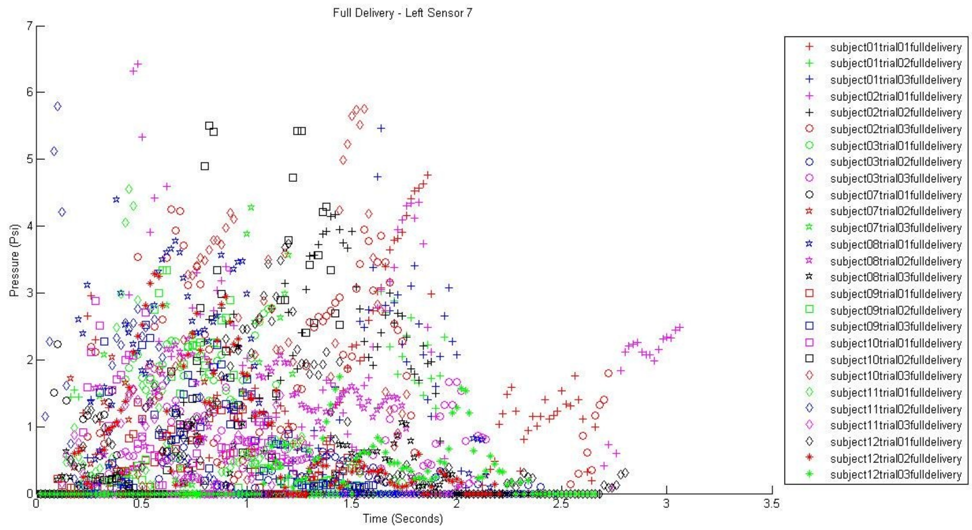
Full Delivery - Left Sensor 7
Pressure (Psi)
Time (Seconds)
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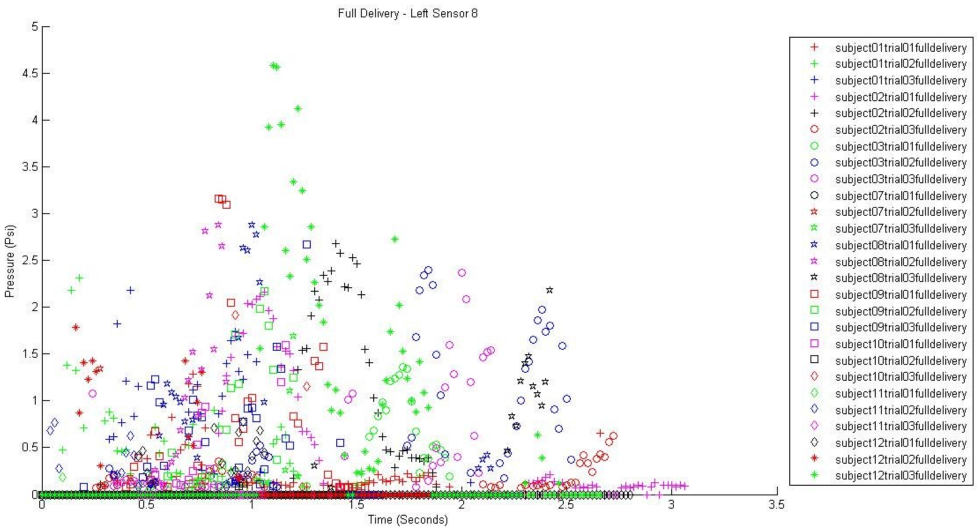
Full Delivery - Left Sensor 8
Pressure (Psi)
Time (Seconds)
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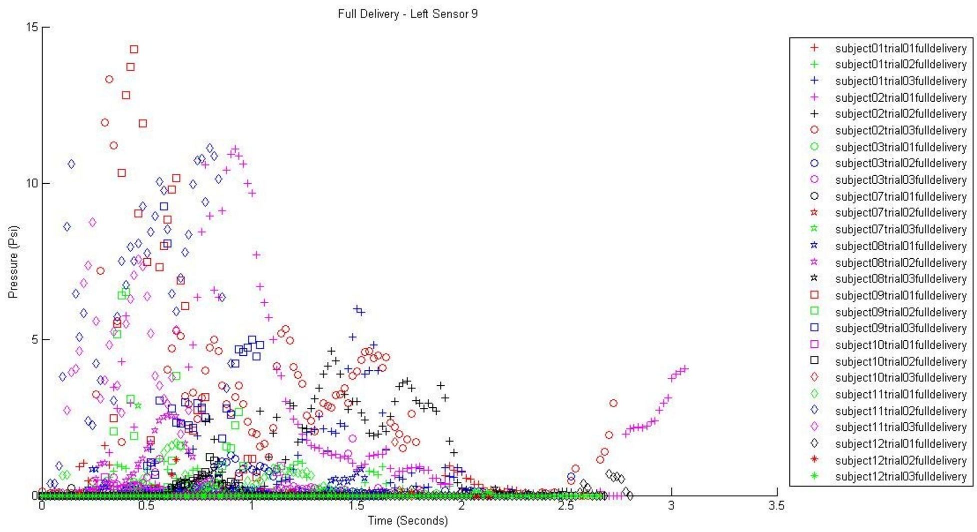
Full Delivery - Left Sensor 9
Pressure (Psi)
Time (Seconds)
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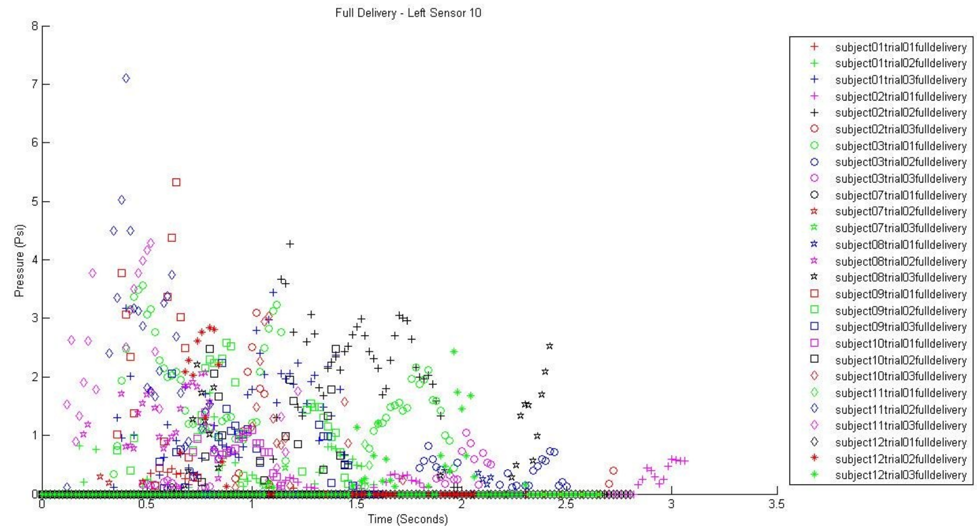
Full Delivery - Left Sensor 10
Pressure (Psi)
Time (Seconds)
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subject01trial02fulldelivery
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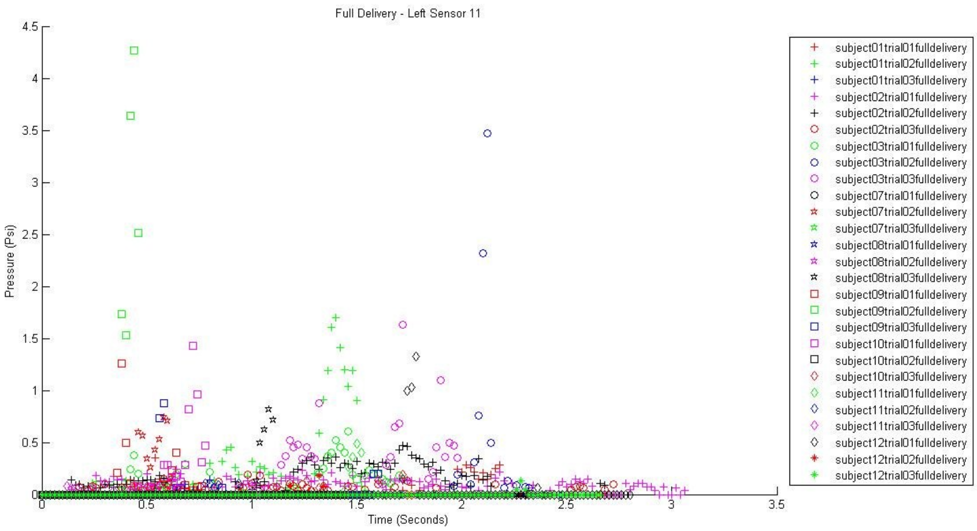
Full Delivery - Left Sensor 11
Pressure (Psi)
Time (Seconds)
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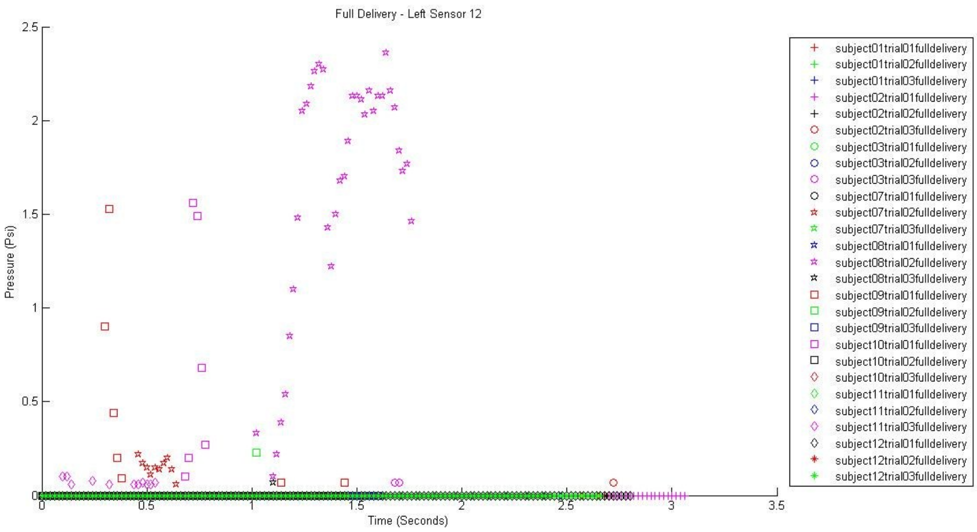
Full Delivery - Left Sensor 12
Pressure (Psi)
Time (Seconds)
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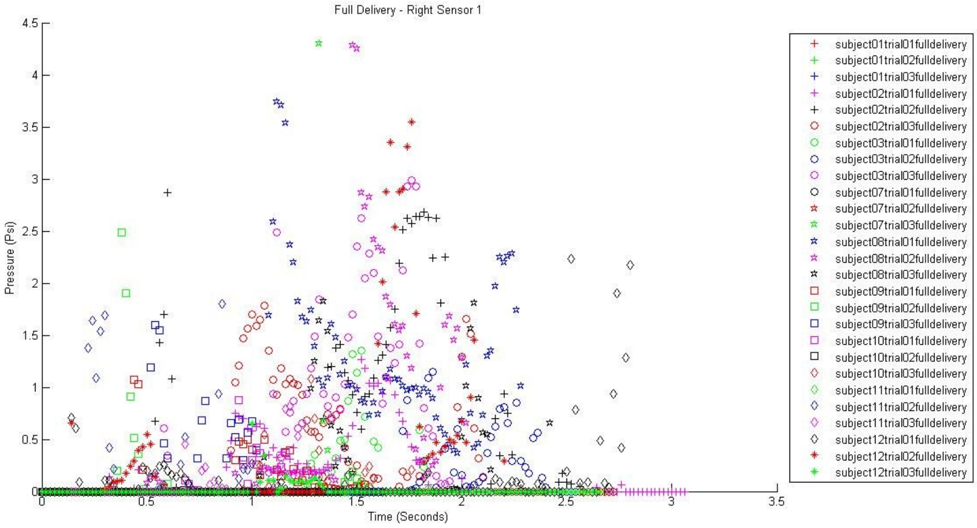
Full Delivery - Right Sensor 1
Pressure (Psi)
Time (Seconds)
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subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
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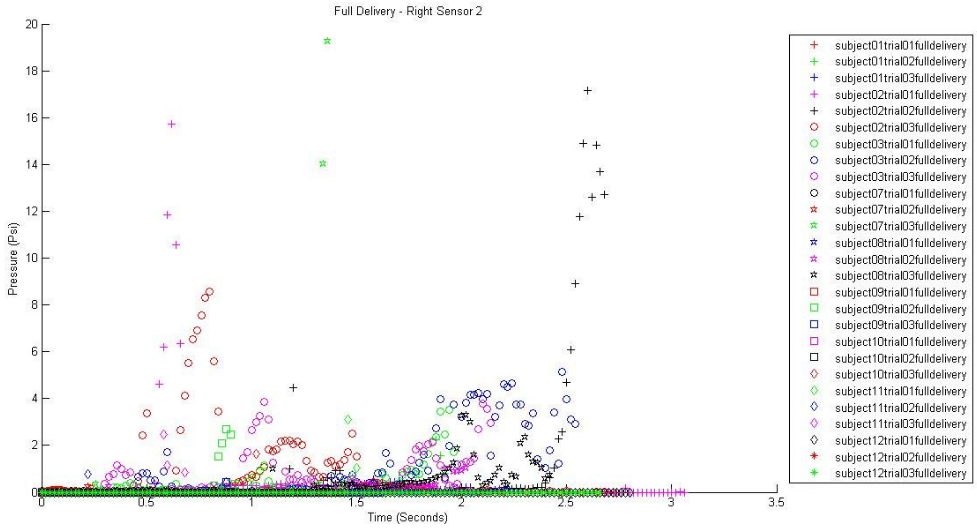
Full Delivery - Right Sensor 2
Pressure (Psi)
Time (Seconds)
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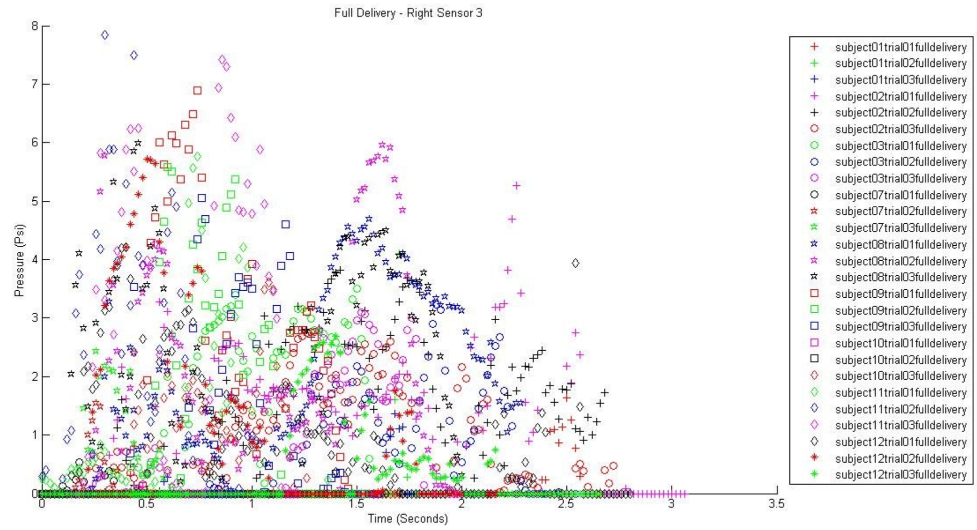
Full Delivery - Right Sensor 3
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
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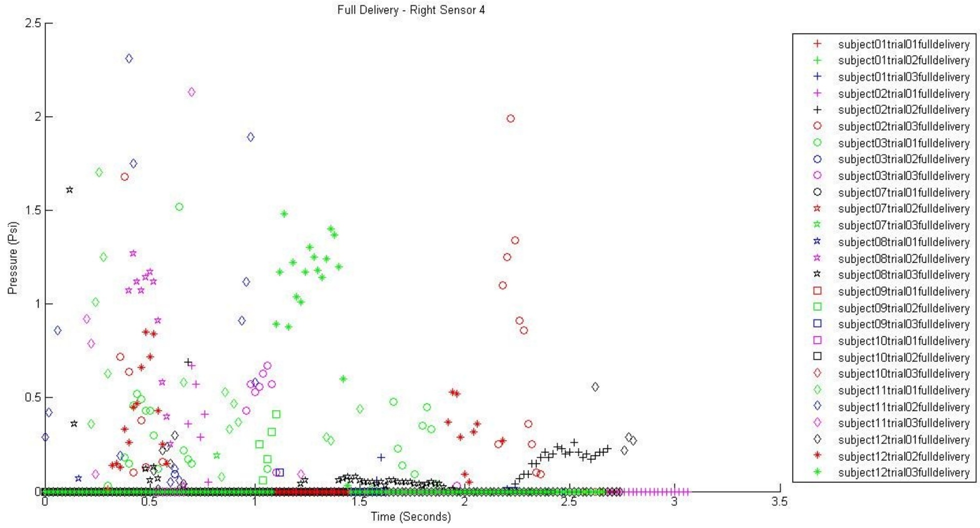
Full Delivery - Right Sensor 4
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
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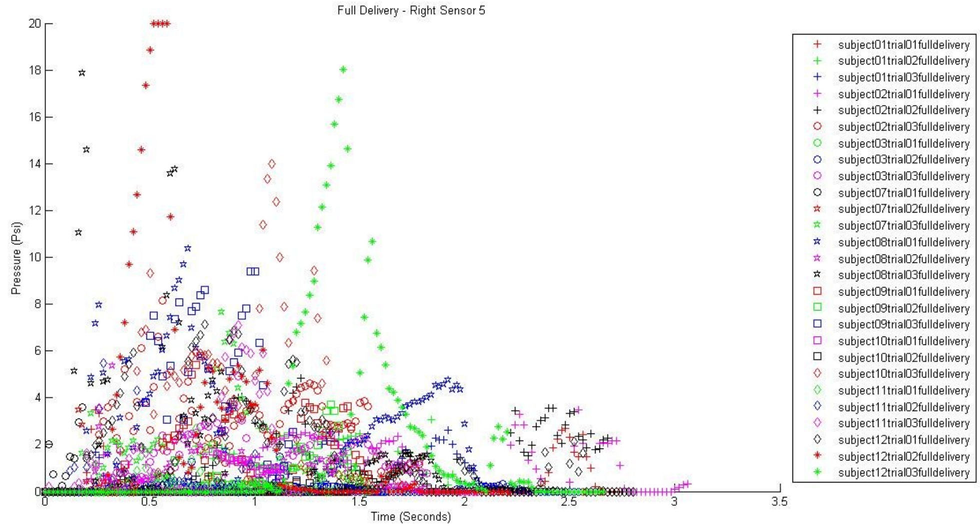
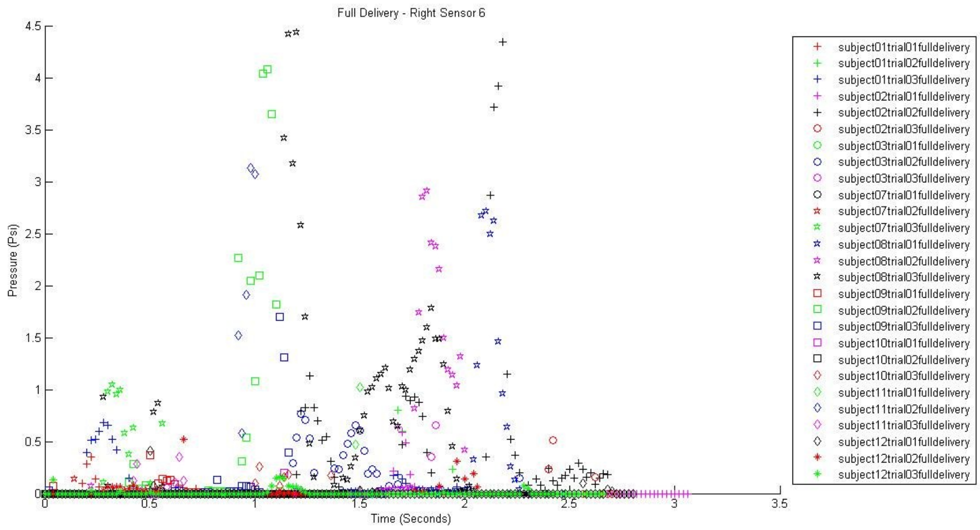
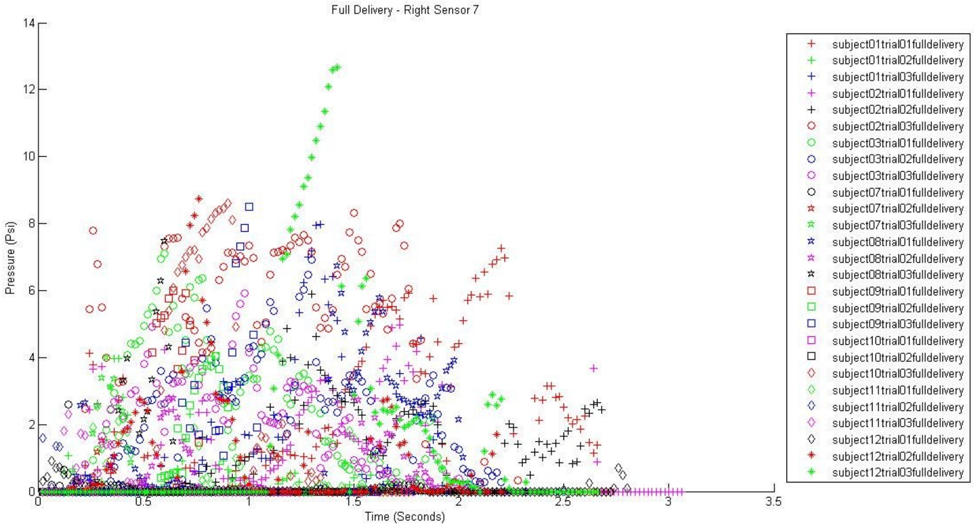
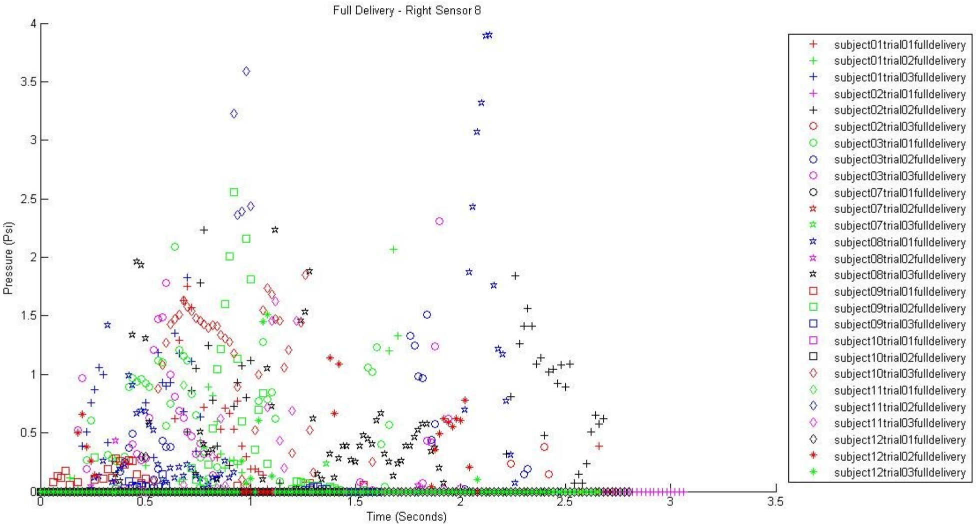
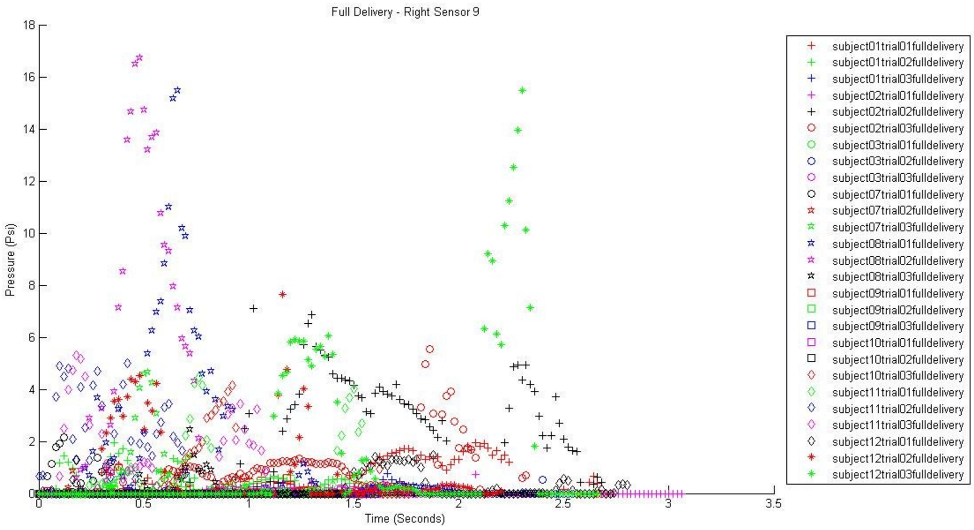
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery

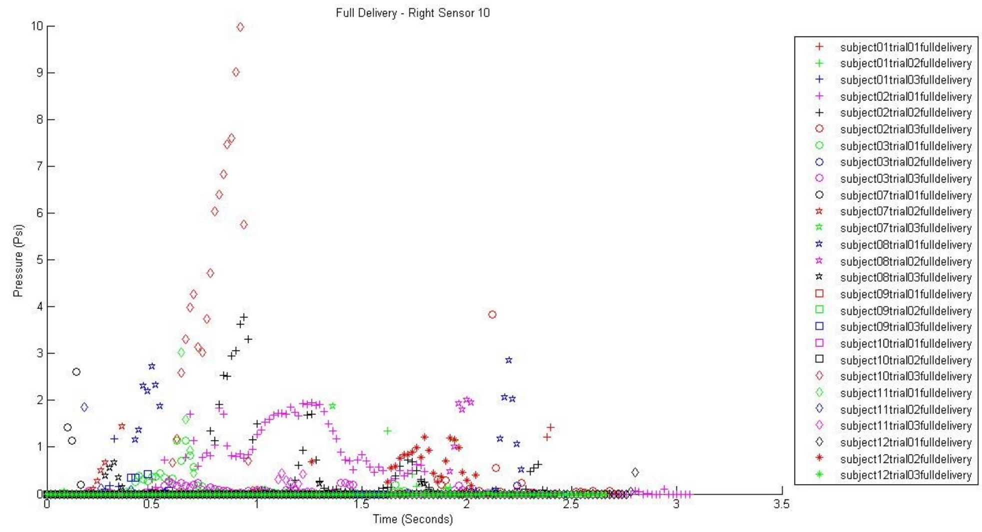

Full Delivery - Right Sensor 5
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery

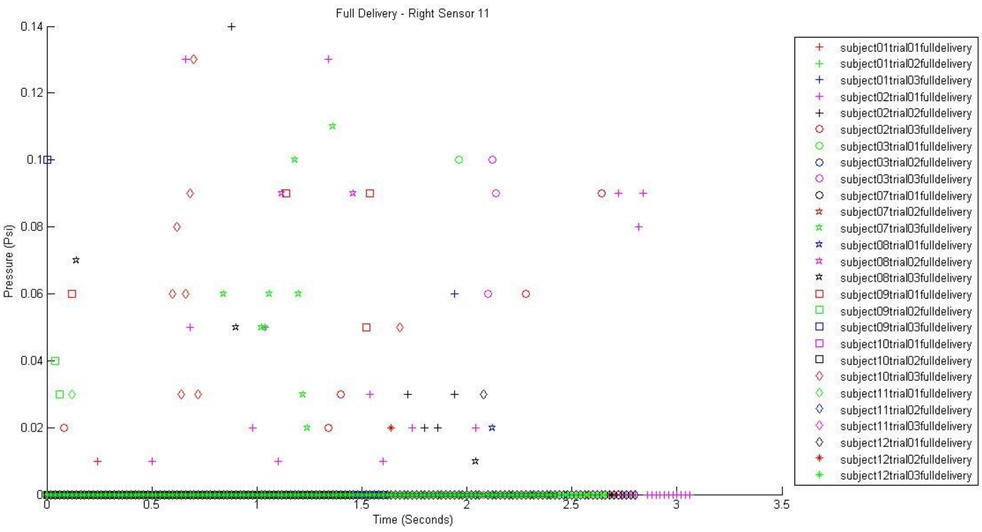

Full Delivery - Right Sensor 6
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery

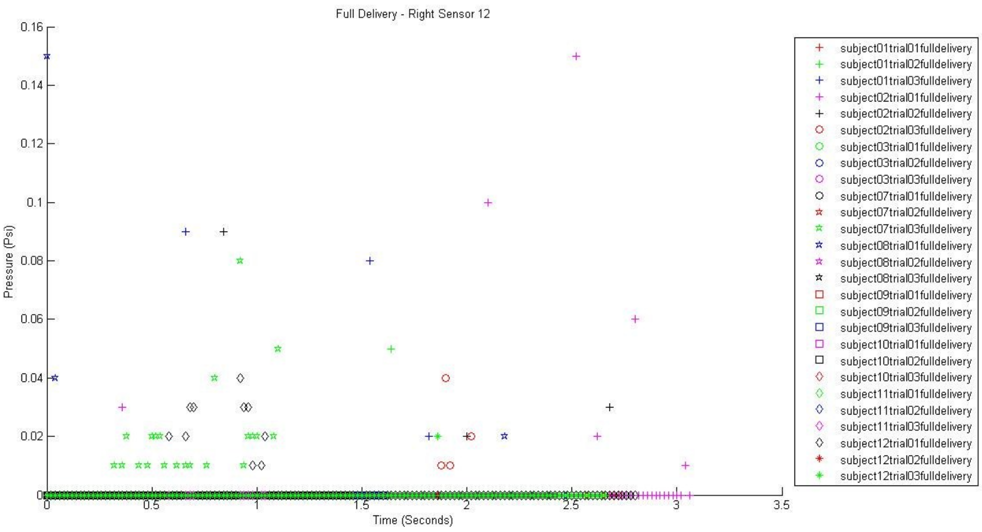

Full Delivery - Right Sensor 7
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery


Full Delivery - Right Sensor 8
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery


Full Delivery - Right Sensor 9
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery


Full Delivery - Right Sensor 10
Pressure (Psi)
Time (Seconds)
subject01trial01fulldelivery
subject01trial02fulldelivery
subject01trial03fulldelivery
subject02trial01fulldelivery
subject02trial02fulldelivery
subject02trial03fulldelivery
subject03trial01fulldelivery
subject03trial02fulldelivery
subject03trial03fulldelivery
subject07trial01fulldelivery
subject07trial02fulldelivery
subject07trial03fulldelivery
subject08trial01fulldelivery
subject08trial02fulldelivery
subject08trial03fulldelivery
subject09trial01fulldelivery
subject09trial02fulldelivery
subject09trial03fulldelivery
subject10trial01fulldelivery
subject10trial02fulldelivery
subject10trial03fulldelivery
subject11trial01fulldelivery
subject11trial02fulldelivery
subject11trial03fulldelivery
subject12trial01fulldelivery
subject12trial02fulldelivery
subject12trial03fulldelivery


Full Delivery - Right Sensor 11
Pressure (Psi)
Time (Seconds)


Full Delivery - Right Sensor 12
Pressure (Psi)
Time (Seconds)

A.5: MATLAB script for statistical processing of sensor data that exceeds 20 psi

```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Traction Only Peaks\n\n')

% read in Excel files
names={'subject01trial01tractiononly',
  'subject01trial02tractiononly',
  'subject02trial01tractiononly',
  'subject02trial02tractiononly',
  'subject02trial03tractiononly',
  'subject03trial01tractiononly',
  'subject03trial02tractiononly',
  'subject03trial03tractiononly',
  'subject05trial01tractiononly',
  'subject05trial02tractiononly',
  'subject05trial03tractiononly',
  'subject07trial01tractiononly',
  'subject07trial02tractiononly',
  'subject07trial03tractiononly',
  'subject08trial01tractiononly',
  'subject08trial02tractiononly',
  'subject08trial03tractiononly',
  'subject09trial01tractiononly',
  'subject09trial02tractiononly',
  'subject09trial03tractiononly',
  'subject10trial01tractiononly',
  'subject10trial02tractiononly',
  'subject10trial03tractiononly',
  'subject11trial01tractiononly',
  'subject11trial02tractiononly',
  'subject11trial03tractiononly',
  'subject11trial04tractiononly',
  'subject12trial01tractiononly',
  'subject12trial02tractiononly',
  'subject12trial03tractiononly'};
l=length(names);
% Subject 1 only did two sets of this trial.
% Subject 11 did four sets of this trial.
% Everyone else did the standard three sets.

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+13),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+13),:))
        if S((i+13),j)==20.00
```

```
          counter(h,i)=counter(h,i)+1;
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
            Of|%f\n',names{h},
            i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+13),:))
            ))
  end
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+36),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+36),:))
        if S((i+13),j)==20.00
          counter(h,i)=counter(h,i)+1;
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
            Of|%f\n',names{h},
            i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+36),:))
            ))
  end
end
```

```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Excessive Force Peaks\n\n')

% read in Excel files
names={'subject01trialbad',
  'subject02trialbad',
  'subject03trialbad',
  'subject05trialbad',
  'subject07trialbad',
  'subject08trialbad',
  'subject09trialbad',
  'subject10trialbad',
  'subject11trialbad',
  'subject12trialbad'};
```

```
l=length(names);

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+13),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+13),:))
        if S((i+13),j)==20.00
          counter(h,i)=counter(h,i)+1;
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
Of|%f\n',names{h},
i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+13),:))))
  end
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+36),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+36),:))
        if S((i+13),j)==20.00
          counter(h,i)=counter(h,i)+1;
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
Of|%f\n',names{h},
i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+36),:))))
  end
end
```

```
% get rid of old variables and clean up window
clear all;
close all;
clc;

format long

% explain what this is
fprintf('Full Delivery Peaks\n\n')

% read in Excel files
```

```
names={'subject01trial01fulldelivery',
  'subject01trial02fulldelivery',
  'subject01trial03fulldelivery',
  'subject02trial01fulldelivery',
  'subject02trial02fulldelivery',
  'subject02trial03fulldelivery',
  'subject03trial01fulldelivery',
  'subject03trial02fulldelivery',
  'subject03trial03fulldelivery',
  'subject07trial01fulldelivery',
  'subject07trial02fulldelivery',
  'subject07trial03fulldelivery',
  'subject08trial01fulldelivery',
  'subject08trial02fulldelivery',
  'subject08trial03fulldelivery',
  'subject09trial01fulldelivery',
  'subject09trial02fulldelivery',
  'subject09trial03fulldelivery',
  'subject10trial01fulldelivery',
  'subject10trial02fulldelivery',
  'subject10trial03fulldelivery',
  'subject11trial01fulldelivery',
  'subject11trial02fulldelivery',
  'subject11trial03fulldelivery',
  'subject12trial01fulldelivery',
  'subject12trial02fulldelivery',
  'subject12trial03fulldelivery'};
l=length(names);

% get a bunch of statistics
for h=1:1:l
S=xlsread(strcat('',names{h},'.xls'));
% S(14,:) through S(25,:) are the left pressure data values
% S(37,:) through S(48,:) are the right pressure data values
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+13),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+13),:))
        if S((i+13),j)==20.00
          counter(h,i)=counter(h,i)+1;
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+13),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
Of|%f\n',names{h},
i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+13),:))))
  end
  for i=1:1:12 % each hand has 12 sensor values
    if max(S((i+36),:))==20.00
      counter(h,i)=0;
      for j=1:1:length(S((i+36),:))
        if S((i+13),j)==20.00
          counter(h,i)=counter(h,i)+1;
```

```
        else
        end
      end
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    else
      counter(h,i)=0;
      ratio_of_peaks(h,i)=counter(h,i)/length(nonzeros(S((i+36),:)));
    end
    fprintf('%s|Left Sensor %g|Ratio of Peaks|%f|Counter|%f|Out
Of|%f\n',names{h},
i,ratio_of_peaks(h,i),counter(h,i),length(nonzeros(S((i+36),:))))
  end
end
```