

**A Designers Perspective on Decreasing  
Anterior Cruciate Ligament Injuries Through the  
Informed Design of an Interactive Training Device**

by

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## Abstract

Young adults frequently engage in various physically demanding sports without the training or supervision of a trained professional. This lack of training or supervision frequently leads athletes to practice and play with unconditioned bodies and incorrect form. Such acts typically lead to injury. The purpose of this thesis is to create principles that will identify physical attributes that increase an athlete's rate of injury and create a training device that emphasizes form and lowers the chance of injury. The creation of this device will be directed towards sports that require agility, pivoting, cutting, and quick acceleration and deceleration. Participating in these sports increases one's susceptibility to leg injuries. One of the most frequent and misunderstood injuries for this age group is the non-contact ACL (Anterior Cruciate Ligament) tear; it will be the focus of the thesis. The following information will provide young adult athletes and athletic instructors with the knowledge of how to lessen the frequency of ligament and tendon injuries and provide designers with the knowledge to create devices that assist in the training and protection of the athlete.

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## List of Abbreviations

ACL	Anterior Cruciate Ligament
PCL	Posterior Cruciate Ligament
MCL	Medial Collateral Ligament
LCL	Lateral Collateral Ligament

## CHAPTER 1: INTRODUCTION TO PROBLEM

### 1.1 Problem Statement

Numerous college-aged athletes in the United States suffer from lifestyle-altering leg injuries each year. In the more serious instances, it is not the quickly regenerating muscle fibers that are damaged, but the more debilitating soft tissues like ligaments and tendons. These injuries not only require elaborate diagnosis procedures, painful surgeries, and months of rehabilitation, but they also can lead to early arthritis in the injured joint. "Chronic knee problems, such as instability, meniscal and chondral surface damage, and osteoarthritis (OA), are often the result of a previous ACL rupture," states researcher Flynn (2005).

Many young adults who come out of highly athletic high school agendas seek to continue their active lifestyle so they can enjoy competition and interact with new people. If these individuals are not recruited by a college-funded athletic program, they typically lack the training and instruction to compete at their previous level of athleticism. Most high school sports programs do a sufficient job of physically preparing these young adults for athletic competition but fail to inform them of the importance of injury preventative exercises. Two researchers, Garrett and Yu, deduced that "[p]roper coaching techniques seem to emphasize

performance and often do not emphasize injury prevention" (Garrett Jr. & Yu, 2007). The individuals who participate in various types of athletics without correct preparation often suffer serious lifestyle changing injuries. Furthermore, there has been an over-emphasis on rehabilitation and bracing for post-operative leg injuries instead of preventing injuries. R. Bahr of the Oslo Sports Trauma Research Center states that "whereas developing improved treatment methods for injuries remains an important goal, it may be even more important to prevent injuries" (2003). The goal of this project is to develop a protocol for identifying college-aged athletes who may be susceptible to knee injuries and design a preventative training device that lowers the chance of injury.

## **1.2 Need for Study**

It is anticipated that each year "anywhere from 75,000 to over 250,000 individuals in the United States will suffer a new injury to the anterior cruciate ligament (ACL) of the knee" (Hewett, 2007). One website estimated that for "patients not covered by health insurance, the cost of ACL reconstruction, including the surgeon's fee, facility fee, anesthesia and graft, if needed, ranges from just under \$20,000 to \$50,000" (ACL Reconstruction Cost, 2009). On top of that, there are still costs for crutches, braces, and physical rehabilitation.

The need for this project is to develop an assessment and training protocol that may identify potential injurious movement mechanics and provide a method for the retraining of those mechanics. This project will provide insightful

information to the athletic community as well as to individuals who need to be aware of the elevated risk of sustaining a serious knee injury. By identifying athletes who are susceptible to knee injuries and offering exercises by which such risk may be decreased, there will be information to provide athletic trainers, coaches, and athletes with the knowledge to address potential precursors to such injuries. In addition, the methods used by this project will provide designers insightful information on how to better design equipment for injury prevention by applying research, by tailoring personal training protocols to an individual's anatomical weaknesses, and creating devices that teach correct athletic form. The implementation of this knowledge would ideally bring about significantly lowered cases of ACL injuries and save families, sporting departments, and insurance companies thousands of dollars each year.

### **1.3 Objectives of Study**

The objective of this document is to study the causes of ACL tears in the young adult athlete, ages 16 through 28. The research will identify what characteristics a person may possess that makes them more susceptible to an ACL injury. It will also study current successful prevention programs, taking the most effective exercises and applying them to a training device that can instruct and correct an athlete's dynamic movements in real time.

- Study causes of ACL tears in noncontact situations.

- Discover relation of injury due to incorrect technique, poor stature, lack of coordination or reaction time, or anatomical deficiencies.
- Research possible flaws in athletic products that lead to knee injuries.
- Create a guideline that explains how to create or select training equipment based on multiple inputs with the purpose of decreasing noncontact, soft tissue injuries. The guideline also will be applicable for decreasing noncontact, soft tissue injuries in a wide range of athletics.
- Make a product that applies the guidelines set by the documentation and incorporates the exercises proven to reduce one's susceptibility to an ACL tear. The exercises performed on the training device should be tailored to the athletes' sport and position of choosing and take into consideration any elevated risk factors that the athlete possesses.

#### **1.4 Definition of Key Terms**

**Abduction** - Any lateral movement of a segment away from the midline of the trunk, as in raising the arms or legs to the side horizontally.

**Adduction** - Any medial lateral movement of a segment towards the midline of the trunk, as in lowering the arms to the side or legs back to the anatomical position.

**Anatomical Neutral Position** - The position of reference in which the subject is in the standing position, with feet shoulder-width apart and palms of hands facing forward.



**Anteroposterior axis** - The axis that has the same directional orientation as the sagittal plane of motion and runs from front to back at a right angle to the frontal plane of motion. Also known as the sagittal or AP axis (Floyd, 2007).

**Lateral flexion** - Movement of the head and/or trunk laterally away from the midline (Floyd, 2007).

**Anterior Cruciate Ligament (ACL)** - A stabilizing ligament within the center of the knee joint whose main role is to prevent anterior translation of the tibia on the femur.

**Closed chain motion** - A movement that generates torsional stress on a joint when the distal joint member is fixed and the proximal member moves.

**Cruciate** - The ACL and PCL cross each other inside the knee, forming an "X." They are called the "cruciate" because they form a cross-like structure.

**Distal** - Located far from the point of reference or point of attachment.

**Etiology** (alternatively **aetiology**, **aitiology**) - The study of why things occur, or to study the reasons things act a certain way, causation.

**Femur** - The upper leg or thighbone, which extends into the hip socket at its upper end and down to the knee at its lower end.

**Fibula** - The thin, outer bone of the leg that forms part of the ankle joint at its lower end.

**Fibrocartilage** - The tough, very strong tissue found predominantly in the intervertebral disks and at the insertions of ligaments and tendons.

**Hip** - A ball and socket joint that consist of the head of the femur connecting with the acetabulum of the pelvic girdle. Its main functions are bearing weight and locomotion (Floyd, 2007).

**Hyperextension** - The extension of a limb or body part farther than what is done on a normal basis.

**Indirect Sport Injury** - Those injuries that were caused by systemic failure as a result of exertion while participating in a sport activity or by a complication that was secondary to a non-fatal injury (Mueller, 2001).

**Injury** - A physical harm or damage to the body resulting from an exchange, usually acute, of mechanical, chemical, thermal, or other environmental energy that exceeds the body's tolerance.

**Joint** - A junction where two bones meet.

**Kinesiophobia** - The fear of pain or painful reinjury.

**Ligament** - A type of rough connective tissue that attaches bone to bone to provide static stability to joints (Floyd, 2007).

**Lateral Collateral Ligament (LCL)** - Ligament of the knee along the lateral aspect that connects the femur to the fibula. It provides lateral stability to the joint.

**Medial Collateral Ligament (MCL)** - Ligament of knee along the medial aspect that connects the femur to the joint.

**Median** - Relating to, located in, or extending toward the middle, situated in the middle, mesial (Floyd, 2007).

**Meniscus** - Crescent shaped cartilage, usually pertaining to the knee joint; also known as "cartilage." There are two menisci in the knee, medial and lateral.

These work to absorb weight within the knee and provide stability (Cluett, 2008).

**Muscle** - Tissue composed of bundles of specialized cells that contract and produce movement when stimulated by nerve impulses.

**Musculoskeletal System** - The body's muscles, bones, tendons, and ligaments.

**Noncontact injury** - Injuries that are not the result of a collision, typically resulting from landing, twisting, and planting.

**Posterior Cruciate Ligament (PCL)** - A stabilizing ligament within the center of the knee joint whose main role is to prevent posterior translation of the tibia on the femur.

**Physical Activity** - Movement created by skeletal muscle contractions, resulting in energy expenditure.

**Physical Training** - An organized exercise intended to enhance fitness. The terms exercise and physical training are used interchangeably.

**Patella** - Otherwise known as the kneecap. It is a flat, triangular bone, which sits on the front of the knee joint. It serves to increase the mechanical advantage and force generating capacities of the quadriceps. It also dissipates any force placed upon it evenly throughout the knee.

**Plyometrics** - A type of exercise training designed to produce fast, powerful movements, and improve the functions of the nervous system.

**Prophylactic** - A device used in protecting from or preventing against a disease or injury.

**Proprioception** - Feedback relative to tension, length, and contraction state of muscle, the position of the body and its limbs, and movements of the joints provided by internal receptors located in the skin, joints, muscles, and tendons.

**Proximal** - Nearer to the point of reference or point of attachment.

**Range-of-motion (ROM)** - The specific amount of movement possible in a joint.

**Sagittal plane** - Plane that separates the body from front to back, dividing it into right and left halves. Also known as the AP plane.

**Self-efficacy** - The belief in one's ability to succeed in specific situations. One's sense of self-efficacy can play a major role in how one approaches goals, tasks, and challenges.

**Sport** - Physical activity that is governed by a set of rules or customs and often engaged in competitively.

**Sprain** - An injury to a ligament, a stretching or a tearing. One or more ligaments can be injured during a sprain. It can be caused by a fall or a force that displaces the joint out of its normal alignment.

**Strain** - An injury to either a muscle or a tendon. They are caused by a quick pull, tear, or twist of the muscle by either overstretching or over-contraction.

**Tendons** - Tough, fibrous cords of tissue that connect muscle to bone.

**Tibia** - The thick, long bone of the lower leg. It forms part of the knee joint at its upper end and the ankle joint at its lower end.

**Valgus knees** - Also known as being knock-kneed.

**Varus knees** - Also known as being bow-legged.

## **1.5 Literature Review**

### **1.5.1. Overview of ACL injury**

Over the past decade, almost every facet of sports and athletics has improved through the application of new technology, the development of new training techniques, and breakthroughs in lighter, stronger materials. These advances have given coaches, sports equipment designers, athletes, and athletic trainers the ability to be better at what they do. However, a disturbing trend has emerged in the realm of sports injury. Instead of emphasizing injury prevention strategies, there is now an overemphasis to address a physical problem once it has occurred. While it is a noble cause to return an injured athlete to an activity that gives them pleasure, would it not be better to avoid serious injuries if, in fact, they were avoidable? Researcher R. Bahr, of the Oslo Sports Trauma Research Center, states that "whereas developing improved treatment methods for injuries remains an important goal, it may be even more important to prevent injuries" (R Bahr, I Holme, 2003).

With all the advancements in athletic equipment and post-operative ligament support, one might wonder why there is so much attention placed on

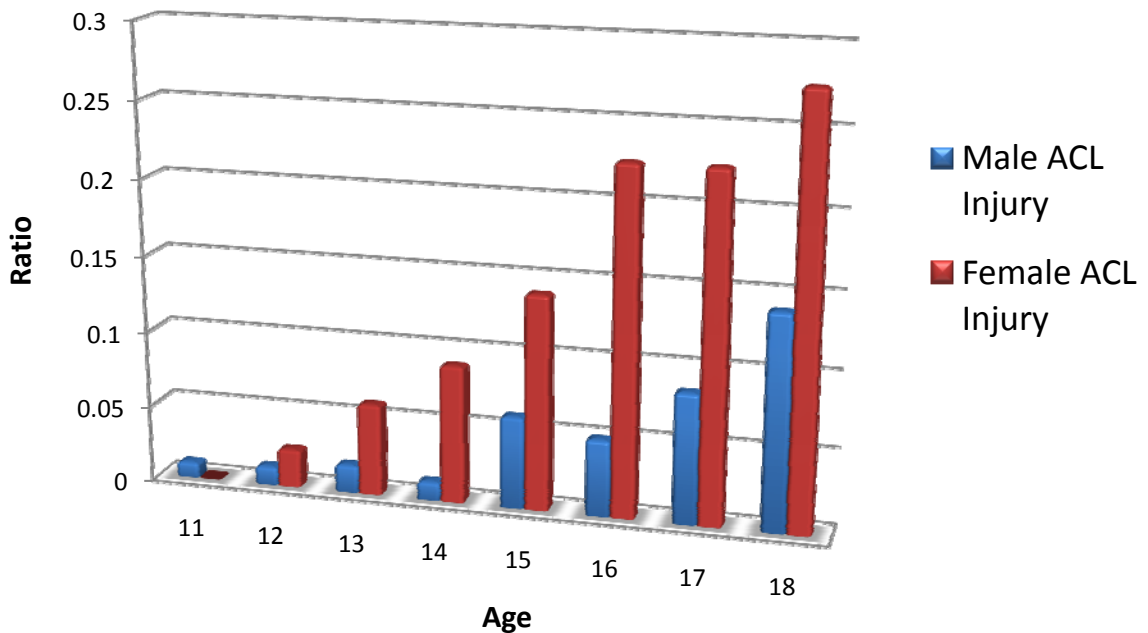
correcting an injury rather than preventing an injury. One study found that “[a]t least 100,000 ACL injuries occur each year in young athletes” (Hewett, 2007). Not only are the rates of injuries high, but so is the cost of reconstructive surgery. Many researchers suggest that “[c]lose to \$1 billion is spent annually on reconstructive surgery alone, which does not include the cost of the initial assessment, the rehabilitation costs after the reconstruction, or the cost of disability insurance” (as cited in Flynn et al., 2005, p.23).

Due to the propensity of the ACL injury and its season-ending potential, it is reasonable to conclude that college-aged athletes would be more aware of the causes of ACL injury. However, due to the push for athletic success at younger and younger ages, most coaches teach techniques that emphasize sports performance and neglect to emphasize exercises that prevent injury (Garrett Jr. & Yu, 2007). The large number of individuals competing at younger ages has led to a large number of athletic young adults who wish to compete throughout their adolescence and into young adulthood. The issue arises when these young athletes are no longer under the supervision and correction of coaches or trainers. This aging, uncoached population frequently engages in high-agility based activities without the knowledge of their increased risk of ACL injury. Currently, there are no organizations that inform young adult athletes about their increased susceptibility to ACL injury.

### 1.5.2. Age Occurrence of ACL Injury

There are two sets of data that display the ages when most female and male athletes acquire an ACL injury. The first set illustrates the “[i]ncidence of claims for ACL injury in youth soccer, as a percentage of all claims” (Marshall, Padua, & McGrath, 2007). The chart reveals that females of the age of 13 have a 0.06 risk of having an ACL injury out of all claimed injuries. This rate jumps to a staggering 0.225 by age 16 and goes on to reach 0.27 ratio of risk by age 18, where the chart terminates. Men, on the other hand, do not reach the risk rate of .06 until the age of 15. This rate continually rises and plateaus at a 0.14 ratio of risk by age 18 (Marshall et al., 2007).

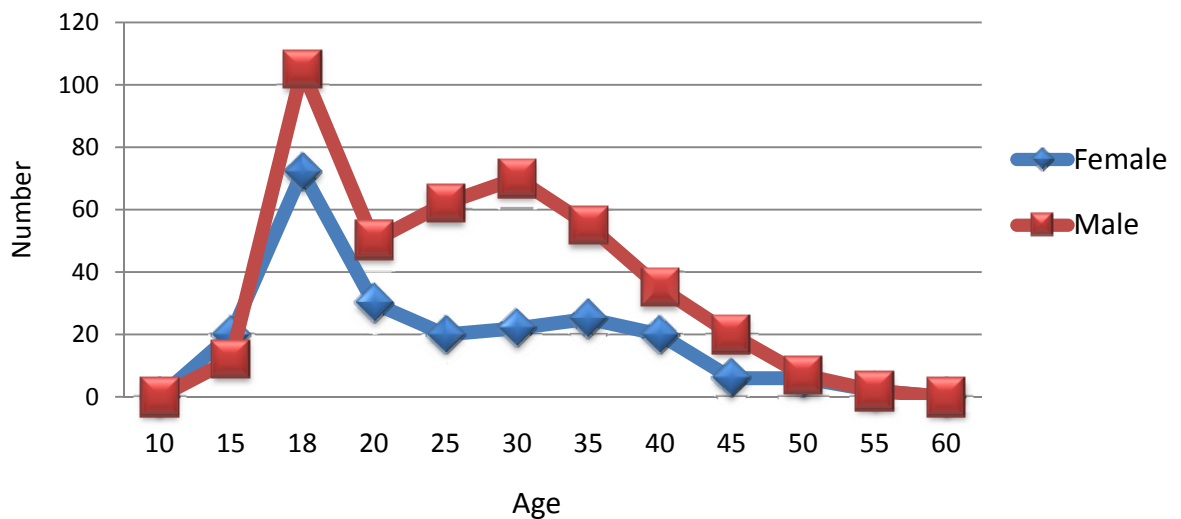
**Ratio of Total ACL Injury Claims to Total Claims**



**Table 1: Ratio of Total ACL Injuries to Total Claims**

The other data set displays the “number of ACL reconstructions performed by candidates for certification before the American Board of Orthopedic Surgeons in 2000” (Marshall et al., 2007). It shows that at age 16, both males and females have undergone approximately 30 ACL repairs. For men, at the age of 18, this rate jumps to a staggering 110 reconstructive surgeries. The rate of occurrence does not begin to steadily decrease until the age of 31. The rate of women’s ACL reconstruction follows a different path. The rate of ACL injuries, for the most part, continually decreases, from a rate of 75 reconstructions to 25 reconstructions at the age of 27. It is important to remember that women still have a higher incidence of ACL injury. From a female perspective, fewer females participate in sports and a larger percentage of these athletes suffer an ACL injury. This is because women are more likely to be predisposed to an ACL injury

### Number of ACL Reconstructions Performed



**Table 2: Number of ACL Reconstructions Performed**



(Cluett, 2008). Drawing from the charts, the ages at which men are most likely to have an ACL injury is between 16-30 while women are most likely to sustain the same injury between the ages of 16 and 22. For this reason, the project will design a solution for young adults between the ages of 16 – 26 years old (Marshall et al., 2007).

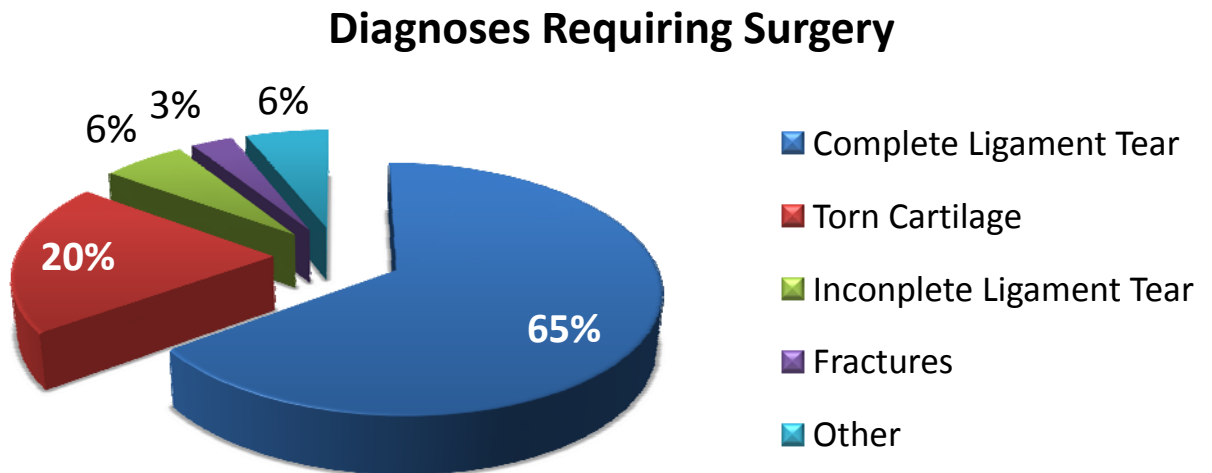
### **1.5.3. Sports with High ACL Risk**

Sports such as basketball, football, and soccer are very popular activities for the young adult age group. These high-agility sports are “considered to be among the higher risk sports for ACL injuries” (Flynn et al., 2005). The knee joints are placed under a lot of strain because actions such as cutting, pivoting, and rapid change of direction are major components in achieving success in each high-agility sport. Weimar, a biomechanics professor at Auburn University, states that the knee joint often succumbs to injury due to its “limited bony and muscular support, its position between the two longest bones in the body, and its frequent use in locomotion” (2009).

A study done by Powell, a professor at Michigan State University, on the frequency of injury in high school athletics revealed that men’s football, soccer, and wrestling had the highest rate of knee injury: football at 15.1%, soccer at 15.1%, and wrestling at 14.8%. The sports that contributed most to knee injury in female athletics were soccer at 19.4%, basketball at 15.7%, and field hockey at 13.7%. Men’s sports that had the highest result of ligament sprains were

basketball at 44.8%, soccer at 32.4%, and football at 31.7%. For female sports, the highest rate of ligament injury came from the sports of volleyball at 51.5%, basketball at 45.2%, and soccer at 38.7 % (Powell & Barber-Foss, 1999).

A similar study concerning high school boys and girls athletics stated that “[s]urgery was required for 16.8% of all knee injuries. The most common diagnoses requiring surgery [major knee injuries] were complete ligament tears (65.5%) and torn cartilage (20.3%)” (Ingram, Fields, Yard, & Comstock, 2008). The sport that caused the most noncontact knee injuries in high school men was basketball, at 6%, and in high school women was soccer at 12%.



**Table 3: Diagnoses Requiring Surgery**

## **1.5.4 Debilitating Nature of ACL Injury**

### **1.5.4.1 Loss of Mobility**

One way ACL injuries can be so detrimental to the varsity age group is by limiting normal mobility. This decrease in mobility regularly leads to a decrease in productivity. After sustaining an ACL injury, most athletes complain of having an unstable knee, trouble walking, and sudden swelling (Cluett, 2008). Therefore, every task that is undertaken is slowed down because of the constant consideration and preservation of the injured knee. Decreased mobility also affects young adults in a social aspect. This age group is widely known for attempting new athletics and resuming favorite sports that they participated in during high school. These activities are a great place for building friendships, interacting with friends, and increasing the social network. Living with a debilitating injury makes it more difficult for an individual to interact with large groups in an active way.

### **1.5.4.2 Wounded Confidence**

Young adults participate in athletics not only for social integration, but also for the physical benefits of being active. After a noncontact injury, many athletes feel like they cannot trust their body. These athletes sometimes suffer from a condition called kinesophobia, which is commonly referred to as fear of reinjury. An article published on fear of ACL reinjury said that “[t]he athletes’ choice not to return to their pre-injury level may depend on the knee function,

but sometimes, social reasons or psychological hindrances such as fear of re-injury may influence their return to sports” (Kvist, Ek, Sporrstedt, & Good, 2005). Sustaining an ACL injury causes an athlete to not only temporarily miss out on new athletic opportunities; it can even prohibit an athlete from benefiting from a lifetime of physical and social interactions.

#### **1.5.4.3. Increase Risk for Osteoarthritis**

ACL injuries not only disrupt immediate social and physical conditions, but they also increase the rate of knee deterioration over one’s lifetime. One study shows that “at 50 years of age, former Australian football players who had previously suffered an ACL tear had a 7 times greater chance of developing moderate-to-severe clinical symptoms of OA [Osteoarthritis] and a 105 times greater chance of developing radiographically diagnosed OA than age matched controls who had no contact sport exposure since their teenage years” (Flynn et al., 2005). The “annual cost of OA in the United States is \$82 billion” (Centers for Disease Control, 2003) and since the knee is the most common site [of injury], it is probably responsible for a large proportion of this financial burden (Marks, Droll, & Cameron-Donaldson, 2007, pg.32). These figures are disturbing because, long after athletes have discontinued participation, they have to deal with a familiar reoccurrence of pain and limited mobility for the remainder of their life.

ACL tears are typically paired with other injuries to the knee and knee capsule. One researcher states that, "knees with acute ACL injuries should be evaluated for meniscus tears as these are identified in approximately 50% of cases" (Busam, 2008). However, if the menisci's inner two-thirds are damaged, it cannot heal itself. The only way to relieve joint locking is to either remove the torn cartilage or to suture it back in place. "Only the outer 1/3 of the meniscus has a blood supply" (p. 4) so its capacity to heal itself is much higher than occasions where "the central 2/3 of the meniscus are not repairable and must have the torn and unstable portion of the meniscus removed" (Miller, 1996, p.4).

#### **1.5.4.4. Successful Recovery Rates Decrease Over Time**

An injury to the ACL is commonly joined with an injury to the meniscus. This happens because part of the ACL is connected to the meniscus. If both parts sustain an injury, the longer the individual waits to get the injury repaired, the lower the chances become of having a successful surgery. One researcher states that:

The success of meniscal repairs in patients with 2 or more years follow-up varies from 62-92%. Egli et al. reported a 27.5% overall failure rate after 7.5 years. Most failures occurred after the first 6 months. Overall, 11% of LM [Lateral Meniscus] tears and 26% of MM [Medial Meniscus] tears failed after surgery (Aiello, 2009).

Prolonged waiting will lessen the chance an individual will ever return to his or her prior activity level.

#### **1.5.4.5 Injured Proprioception**

One final reason why ACL injuries can be so devastating is that they severely interfere with an individual's proprioception. Proprioception is how one's body parts relay information of their position relative to their neighboring body part. Cook, Clinic Director at Orthopedic & Sports Physical Therapy in southwest Virginia, states that the "ACL not only serves a mechanical role by limiting passive knee mobility but also serves a sensory role through the mechanoreceptors deep in its tissue, which communicate with the neuromuscular system to provide proprioceptive feedback during training and competition" (Cook, Burton, & Fields, 1999). A typical symptom of having an ACL tear is complaining of the knee feeling unstable or loose. The injured knee seems to move without the knowledge of its owner. The unstable knee can slip out of its normal track of motion and cause not only uneasiness, but severe pain and injury.

When an individual tears an ACL, the injury is accompanied by a large amount of knee swelling. As a protective mechanism, when the knee joint swells, the quadriceps shut down. The lack of use of the quadriceps quickly leads to muscle atrophy and, consequently, loss of strength. Ho (2009), Associate Professor of Surgery of the Chicago Medical Center, states that "many studies

have shown that it can take up to a year for [proprioception] to come back, whereas you might get your motion and strength back within a couple of months after the surgery” (p. 1). In most cases reconstructive surgery is suggested to ACL deficient, young adult athletes so they can enjoy a lifetime of competitive athletic involvement.

## **1.6 Assumptions**

In this study, information from secondary sources such as books, journals, and internet sources will be used. It is assumed that the information collected from the sources is factual and presented with as little bias as possible. It is assumed that young athletes are not genetically predisposed to soft tissue injuries and these injuries are caused by the person’s physical actions, conscious or unconscious. It is also assumed that no individual will intentionally inflict such an injury upon themselves. The project will also feature some input from primary sources such as designers and biomechanists. It is assumed that all the information from these sources is factual, based on accurate research, and ultimately intended for the overall improvement of the final outcome of the study.

## **1.7 Scope and Limits**

The scope of this study includes young athletes that are between the ages of 16 to 26 who are susceptible to noncontact soft tissue injuries in the leg. The

study will cover how an athlete can have various dispositions that put him or her at a higher risk of an ACL injury. It will also study how athletes train the muscles surrounding the knee, as well as their level of agility and flexibility to lower the risk of injury. This study will not include the psychological effects of injury.

The limits of this study are as follows:

- The study will investigate the mechanisms of the knee and how surrounding bones and muscles affect its range of motion. Spine and hip misalignments that affect normal knee movements will not be considered.
- Design strategies that improve the creation of injury prevention devices will be developed through the writing of this document.
- The testing of the prototype is limited to a pre-prototype model that shows form and basic use.
- The final model is purely a concept that will need further development and technological applications to become a functional product.

## **1.8 Procedures and Methods**

### **Procedure 1:**

Research Anatomy of Knee Joint

Method: Research the anatomical and musculoskeletal structure of the knee joint and find characteristics about its composition and use that make it susceptible to injury.

Analyze Collected Data



Draw Conclusion

**Procedure 2:**

Research Soft Tissue Injuries

Method: Study the composition and use of the soft tissues of the knee, namely the meniscus and the cruciate ligaments, to identify their heightened rate of noncontact injury during agility-based sports in the young adult demographic.

Analyze Collected Data

Draw Conclusion

**Procedure 3:**

Research other factors that contribute to ACL injuries

Method: Examine sports journals and sports injury books and talk with biomechanists that can explain why the ACL is frequently torn and what factors lead to the incident.

Analyze Collected Data

Draw Conclusion

**Procedure 4:**

Discover successful ACL preventative training programs

Method: Review and compile information that is drawn from effective and non-effective ACL prevention programs and

conclude what training routines and movements lead to a decrease in ACL injury.

**Procedure 5:**

Compile information into categories of major factors that lead to an ACL injury based on an athlete's physical anatomy, the athlete's movement tendencies, and the athlete's event of choice.

Method: Consider all factors and decide what the major causes of the injury are. Design a guideline for identifying athletes who are susceptible to ACL injuries. This guideline will be suitable for application to other noncontact injuries in the human body.

**Procedure 6:**

Apply the guideline to the area of noncontact ACL injuries and design a device that could feasibly lower the chance for such an injury.

Method: Prove the feasibility of the guideline by creating a training device that improves athletic technique, strengthens one's physical weaknesses, and brings about awareness of an athlete's personal factors that increases his or her risk of injury. Create a document that visually and verbally explains the problem, definition and need for research study, patterns, design implications, and design solution examples.

## **1.9 Anticipated Outcome**

The anticipated outcome for this project is to provide research so as to further identify what factors of an individual's anatomy makes him or her more susceptible to soft-tissue noncontact leg injuries. It is also important to discover what exercises increase the strength, quickness, and durability of the knee and its supporting structures. The information derived from the research will help develop a guideline that specifies how to create a training program to lessen the elevated risk factors of an athlete. Furthermore, a product or training system will be constructed according to the requirements of the guidelines. The product or training system will take form as a 3D model. Should an athlete use the theoretical final model, he or she should lessen the chances of sustaining a noncontact ACL injury.

## **CHAPTER 2: INTRODUCTION TO RESEARCH**

### **2.1 Overview**

The knee, or tibia femoral joint, at first glance appears to be a very simple joint. It consists of three bones, the femur, the patella, and the tibia. There are also two menisci and four ligaments that hold the knee in place: the ACL (Anterior Cruciate Ligament), the PCL (Posterior Cruciate Ligament), the LCL (Lateral Collateral Ligament) and the MCL (Medial Collateral Ligament). While the quadriceps tendon and the patella ligament hold the patella stationary, the quadriceps and hamstrings muscles give the lower limb its movements of flexion and extension. The legs support the weight of the upper body and give it its great range of mobility. But with a great range of motion, the "combined functions of weight bearing and locomotion place considerable stress and strain on the knee joint" (Floyd, 2007, p. 258). This is a foundational reason why the knee joints are very susceptible to damage.

### **2.2 Anatomy of the Knee**

The knee is categorized as a modified hinge joint. The knee performs two major types of movement, flexion and extension, while also having slight internal and external rotation. The knee is commonly known as a helical joint because it rotates or screws around the larger medial condyle as the knee approaches full

extension. The knee consists of three bones: the femur, which descends from the top and terminates with the formation of the medial and lateral condyle; the tibia, which contacts the knee joint from below, terminating with the tibial plateau; and the patella to the front. These bones are held together by a congregation of internal and external ligaments. The external ligaments connect the patella and the muscle body of the quadriceps to the tibia. The capsular ligament is a thin but strong fibrous membrane that surrounds the joint and fills any areas between the before-mentioned ligaments. The internal ligaments, the ACL and PCL, are situated between the femur and tibia and cross each other, while the LCL connects to the fibula on the lateral side, and the MCL connects the femur to the tibia on the medial side (Gray, 1974, pp. 274-276).

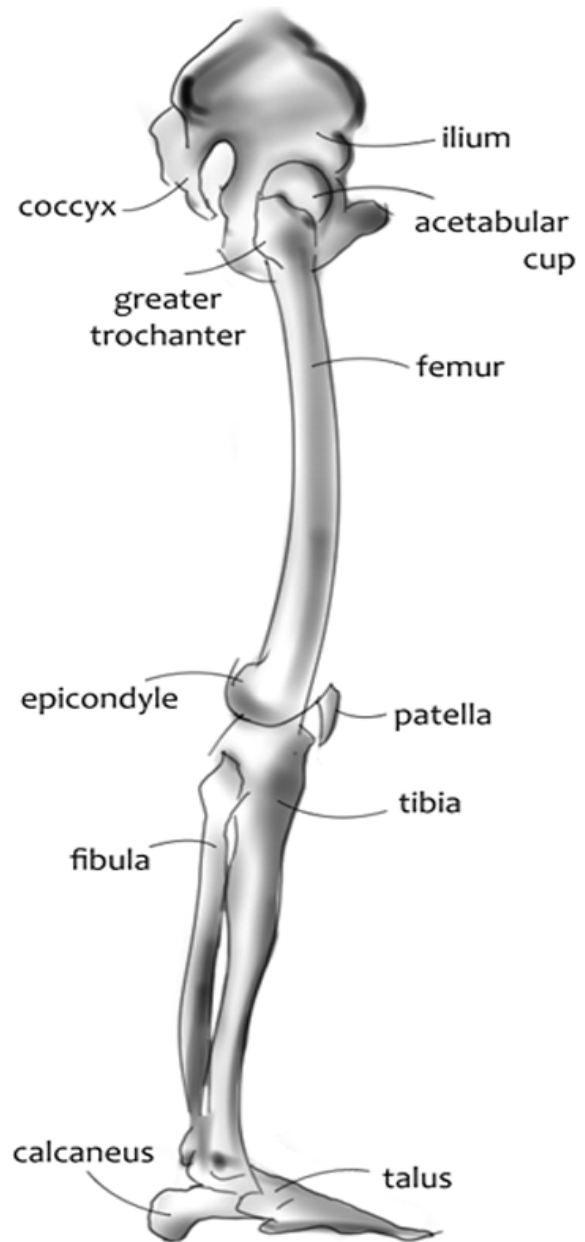
### **2.2.1 Bones**

The femur is the longest bone in the body. It consists of five parts: the head, the greater trochanter, the lesser trochanter, the shaft, and the lower extremity. The head of the femur connects to the acetabular cup of the pelvic girdle. This union is commonly referred to as the hip joint. The lower extremity consists of two separate bony protrusions called condyles, a medial and a lateral. "Due to the shape of the medial femoral condyle, the knee must "screw home" to fully extend." (Floyd, 2007, p. 262) However, in closed chain, this rotational motion takes place at the hip.

In between each condyle, on the anterior surface, there is a smooth depression where the patella rests, called the patellar surface. Underneath and in between the medial and lateral condyle there is a concave surface that is called the intercondylar fossa. This canal harbors “[t]wo very important ligaments of the knee... the anterior and posterior cruciate, so named because they cross within the knee between the tibia and the femur” (Floyd, 2007, p. 260).

The other part of the tibia-femoral joint is called the tibia. It is located below the femur and above the talus bone in the ankle. It is the

second largest bone in the body. It is typically located in a vertical position but sometimes leans inward due to a large “Q” angle. The tibia has a truncated top and bottom where the bone attaches to the knee joint and ankle joint respectively. On the top of the tibia the “medial and lateral tibial plateaus serve as receptacles for the femoral condyles” (Floyd, 2007, p. 258). The tibia contains

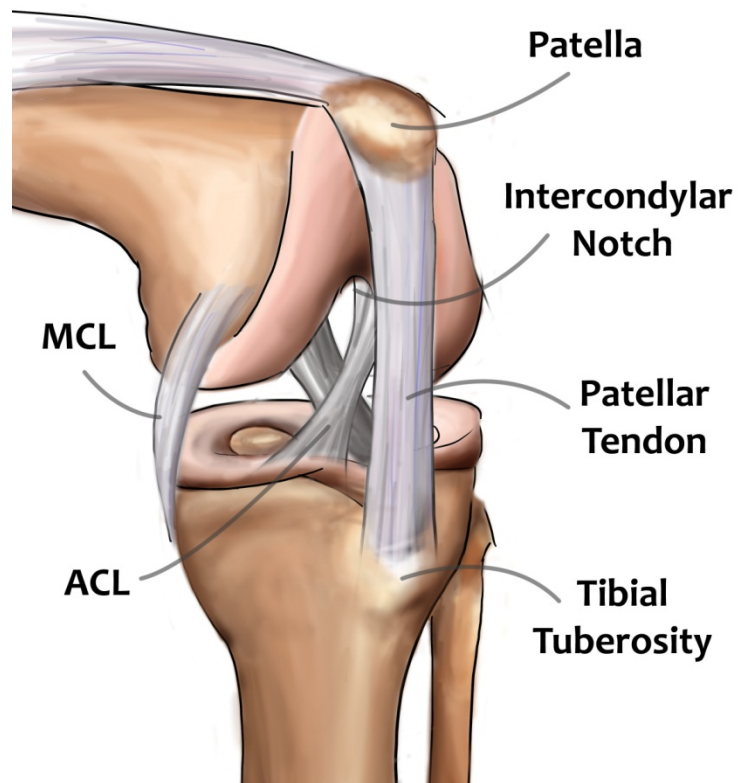


**Illustration 1. Bones of the Leg**

a small, round nub on the anterior surface of the bone; it is called the tibial tuberosity. This protrusion is where the quadriceps muscle is attached via the patella tendon.

The patella, or knee cap, is categorized as a sesmoid, or floating bone. It is connected to the bottom of the quadriceps ligament and the top of the patella tendon. The patella bone possesses an attribute that increases the leg's efficiency. "Its location allows it to serve the quadriceps in a fashion similar to the work of a pulley by creating an improved angle of pull. This results in a greater mechanical

advantage when performing knee extension" (Floyd, 2007, p. 258). The patella also plays a protective role. When the knee joint is struck by an outside force, the patella protects the internal ligaments and soft tissues by dispersing the force to a broader area instead of a



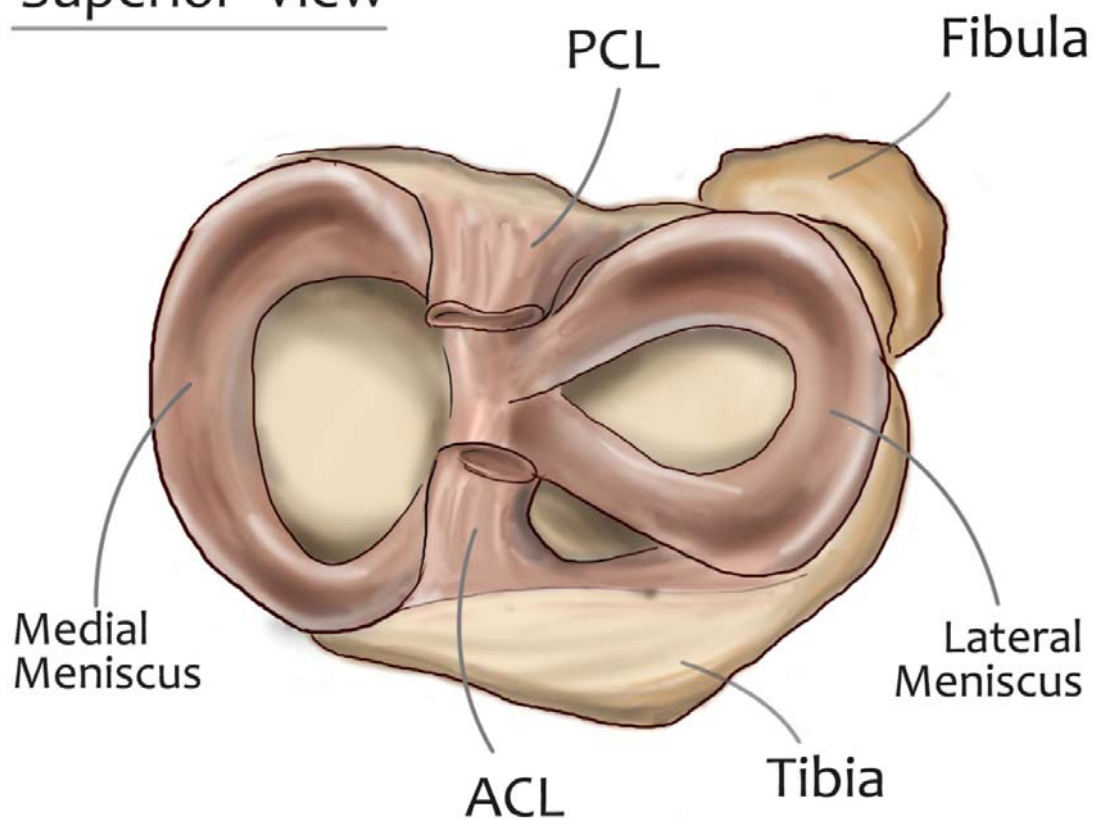
**Illustration 2. Patella and Ligaments**

concentrated point on the femoral condyles or the tibia. (Gray, 1974, p. 280)

### 2.2.2 Soft Tissue

Between the femur and the tibia there two fibro cartilaginous pads called menisci. The larger of the two is called the medial menisci and the smaller one, the lateral menisci. "These menisci are attached to the tibia and deepen the tibial plateaus, thereby enhancing stability" (Floyd, 2007, p. 260). Not only do they enhance stability, but they also serve as a cushion to aid in shock absorption and promote smoothness of movement. "It has been reported that 50%-85% of the

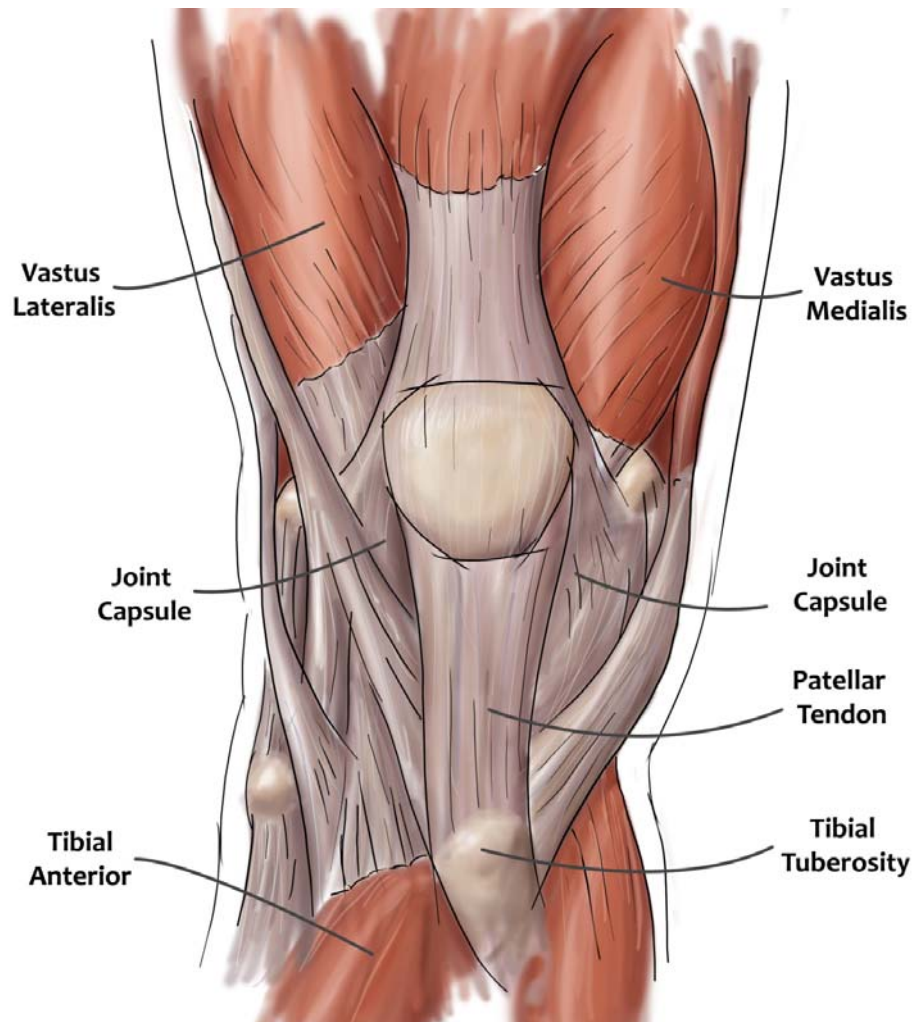
#### Superior View



**Illustration 3. Cartilage and Ligaments**



compressive load placed on the knee joint is transmitted through the meniscus” (Marks et al., 2007, p.33-34). Each menisci forms a “C” shape where the femoral condyles rest. Each one is thick toward its edges but gradually gets thinner as it nears the center. This feature increases surface area contact between the two bones but leaves the inner portion of the meniscus with less regenerative properties (Aiello, 2009, p.4).



**Illustration 4. Joint Capsule**

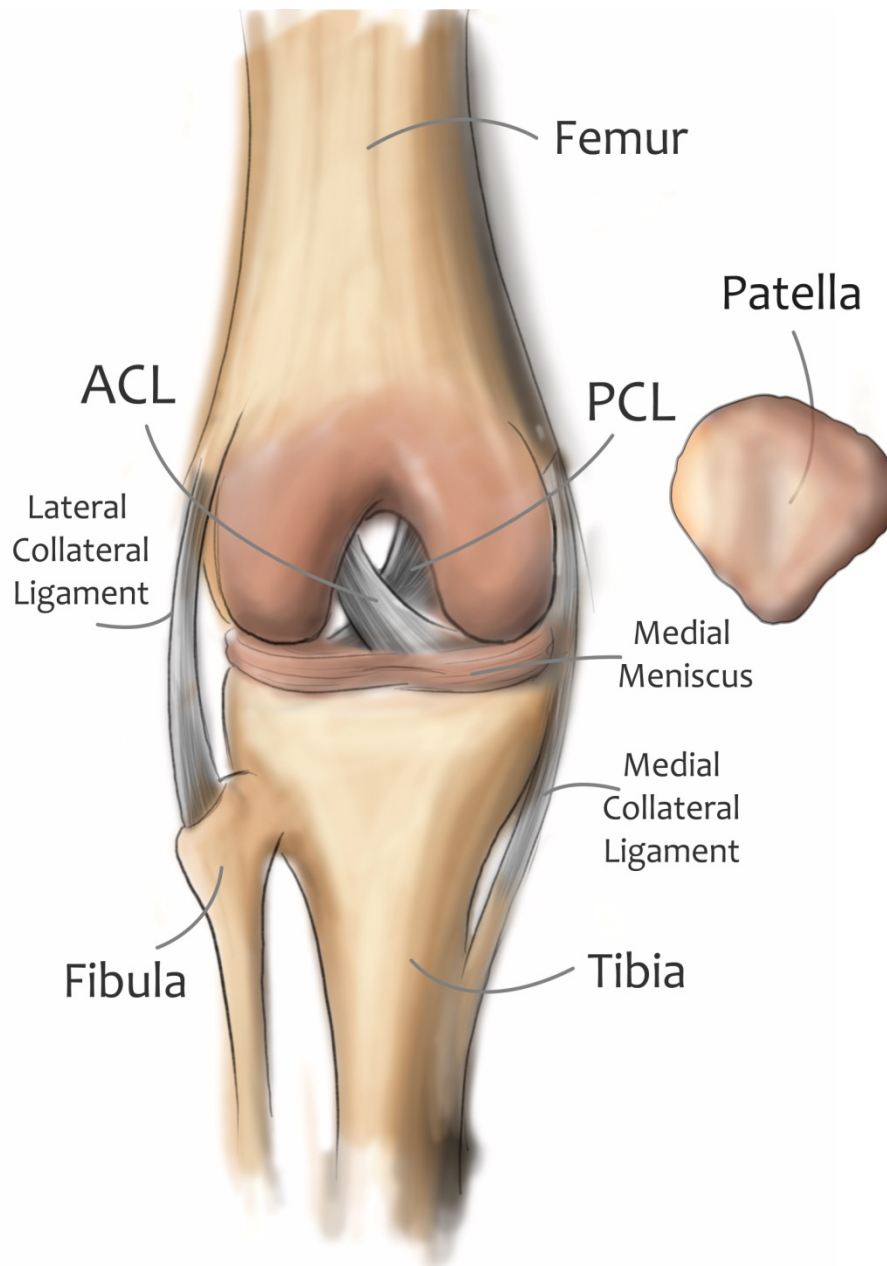
There is a joint capsule that surrounds the bones and ligaments of the knee. It has two layers, an outer fibrous capsule and a delicate thin inner layer. "The fibrous capsule attaches to the walls of the bones that construct the joint" (Lathrop, 2008). It is richly supplied with blood and adheres to its inner layer as well as the four knee ligaments and soft tissue. The delicate thin inner layer is commonly referred to as the synovial membrane. This membrane supplies lubrication between the intersections of the bones thus lowering friction. The synovial membrane is very sensitive and will swell from impact or overuse. Weimar stated that "[o]nce you disrupt the capsule [by surgery], it will never be the same" (2009).

### **2.2.3 Ligaments**

The ACL is one of the primary ligaments that holds the knee joint intact (Hewett, 2007, p.xxi). It originates from the center frontal portion of the tibial plateau and attaches to the posterior base of the femur. It prevents the tibia from moving too far forward when the quadriceps muscle pulls the knee into extension. The ACL also aids in knee stability when the tibia is internally and externally rotated. The PCL is a mirror of the ACL. It "prevents the femur from moving too far forward over the tibia. The PCL is the knee's basic stabilizer and is almost twice as strong as the ACL. It provides a central axis about which the knee rotates" (Stapleton, 2008). While the PCL and ACL regulate anterior and

posterior movement within the knee joint, the MCL and LCL regulate medial and lateral movement of the knee joint.

The MCL is the larger of the two ligaments and is on the inside of the knee, closest to the midline of the body. It originates from the medial condyle of



**Illustration 5. Anterior View of Knee**

the femur and inserts on the inside of the tibia. Furthermore, “[its] deep fibers are attached to the medial meniscus, which may be affected with injuries to the ligament” (Beynon & Slauterbeck, 2007, p. 260). Its purpose is to keep the knee from falling inwards or going into a “valgus” or knock-kneed position. This ligament is most frequently injured when a teammate or opponent falls on the outside of the leg, placing an abnormal amount of force on the medial ligament (Floyd, 2007). The LCL is located on the outside of the knee. It originates from the lateral condyle of the femur and attaches laterally to the head of the fibula. It prevents the knee joint from falling outwards into a “vargus” or bow-legged position. This ligament is rarely injured because an individual seldom takes a blow to the medial side.

### **2.3 Introduction to Injury Causes**

The knee is a very dynamic joint and is “very complex” because of its load bearing qualities (Floyd, 2007). Because of the knee’s complexity, it tends to be susceptible to many types of injuries. If an athlete puts too much strain on a particular tendon or delivers a too great amount of force to a meniscus, he or she can do irreversible damage to the knee joint. However, if all parts are working together in unison, the knee can provide a great range of mobility for the duration of the user’s lifetime. Maintaining strong muscles and proper conditioning, including balance and agility drills, can help keep the joint secure at all ranges of motion.

There is no way to prevent an injury if the causes cannot be identified. An article in The American Sports Journal stated in 2006 that "it is not sufficient to emphasize only prompt recognition and appropriate treatment algorithms, but orthopedic surgeons must develop prevention strategies and verify them using scientific methods" (Griffin et al.,). Van Mechelen, Co-Director at the Institute for Research in Extramural Medicine, stated:

Once it has been recognized through injury surveillance that sports injuries constitute a threat to the health of athletes, the causes must be established as a next step towards injury prevention. This includes information on why a particular athlete may be at risk in a given situation (risk factors) or how injuries happen (as cited in Bahr, Holme, 2003, p.17).

It is important to identify the patterns that lead to a specific sports injury. After these patterns have been established, they can be classified into similar groups. This idea of identifying popular action based on patterns "can potentially be more important and easier to apply to prevent injuries than an exact biomechanical description of joint motion at the point of injury" (Bahr & Holme, 2003).

### **2.3.1 Categorizing Risk Factors**

A way to categorize these patterns of injury is to break them down into two groups of injury-causing factors. The physical characteristics that athletes possess that make them more susceptible to injury are called internal factors. The environment and equipment that affect athletes from the outside of their body are called external factors.

The internal factors will be broken down into groups of anatomical factors, neuromuscular factors, and biomechanical factors. Anatomical factors will address different skeletal shapes and orientations that can increase the risk of injury. Neuromuscular factors will deal with the way that the brain instructs the body to assume different stances while reacting to specific athletic situations. Biomechanical factors will address the way that stress is applied simultaneously as body parts move to many different locations to correct or redirect bodily movement.

External factors will be broken down into groups of meteorological factors, shoe-to-surface interaction, and knee braces. Meteorological factors will deal with the way the weather can affect the quality of playing surface. Shoe-to-surface interaction will address how too much traction can place additional strain to ligaments and limit normal movements. Knee braces will address the effectiveness of preventative braces and their rate of success. The concepts of internal and external risk factors were greatly derived from the causation model developed by Bahr and Krosshaug (Griffin et al., 2006, p. 1521) and TABLE 1

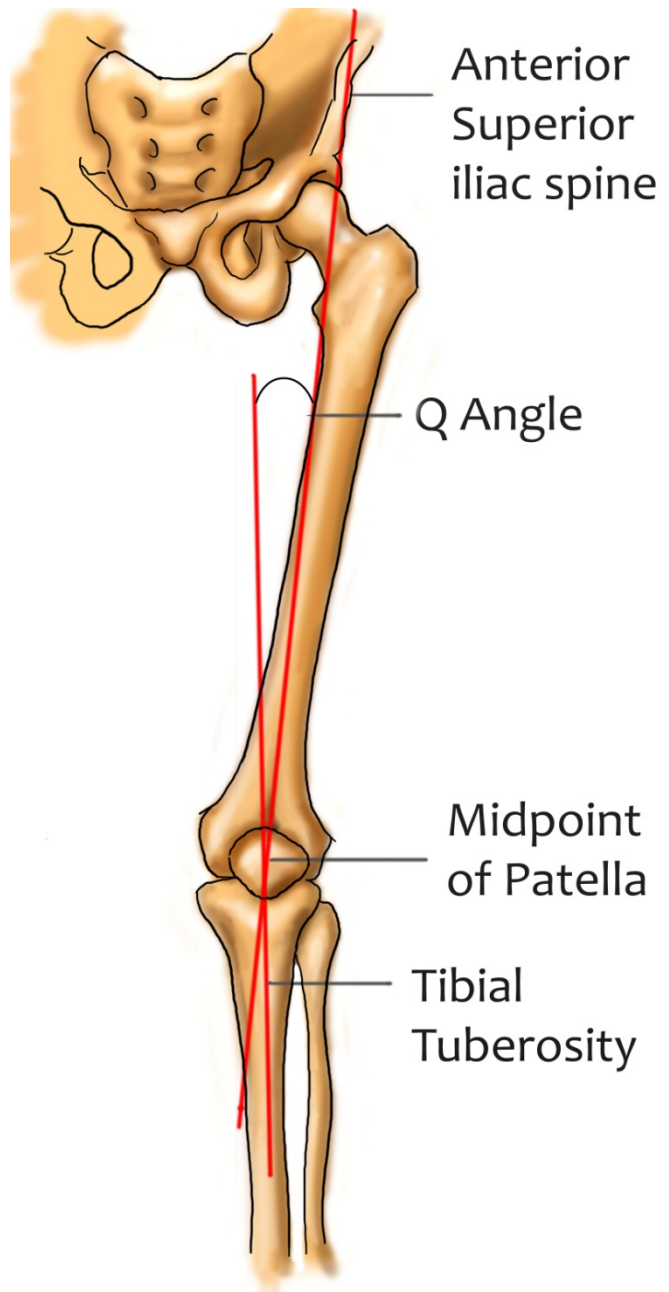
from the Consensus Statement: 1999 Hunt Valley I Meeting (as cited in Griffin et al., 2006, 1514).

### **2.3.2 Anatomical Factors**

A person's body shape does not immediately mean that he or she is susceptible to a specific injury. However, an athlete's limbs may have a specific physical shape or orientation that can increase the chance of having an injury. One example is known as the "Q" angle. It is "defined clinically as the angle in the frontal plane that is formed by intersecting lines from the center of the patella to the anterior superior iliac spine (ASIS) and the center of the patella to the tibial tubercle" (Shultz, Nguyen, & Beynon, 2007, p. 254) More simply, it is the way the femur angles inward from the hip to the knee. Since women typically have wider hips than men, they are more likely to have a greater "Q" angle. This angle increases the rate of injury because women tend to have "less muscular development, especially in the vastus medialis oblique, which plays a crucial role in patella alignment" (Brandon, 2009).

When the patella is internally rotated due to an increased "Q" angle, the internal rotation increases strain on the MCL and the ACL. One study done by Shambaugh investigated a group of 45 basketball athletes by taking various structural measurements and calculated their mean "Q" angle. The study showed that "the mean Q angles of athletes sustaining knee injuries were significantly larger than the mean Q angles for the players who were not injured (14° vs

10°)" (as cited by Griffin et al., 2006, p.1515). Having a larger "Q" angle is not enough, by itself, to cause an injury. However, a larger "Q" angle will increase the likelihood of one's knees assuming a valgus position when performing actions such as landing or cutting. A similar study conducted by Hewett "prospectively followed 205 female athletes participating in the high-risk sports of soccer, basketball, and volleyball... These investigators found that the dynamic knee valgus measures were predictive of future ACL injury risk" (as cited by Griffin et al., 2006, p.1515). The results stated that 73% of individuals who had a greater "Q" angle had ACL-related injuries.



**Illustration 6: "Q" Angle**

Another anatomical trait

that can lead to an ACL injury is walking on the inside of the foot; this is also



called foot pronation. This condition, known as hyperpronation, is identified not only by the "prolonged pronation of the foot and ankle" but doing so "produces excessive internal tibial rotation, and thus may produce a preloading effect on the ACL" (Beckett et al., 1992, p.60). While hyperpronation may not serve as a "significant predictor for ACL injury", it is commonly seen with joint laxity (Griffin et al., 2006, p.1515). The combination of joint laxity and hyperpronation was studied by Woodford-Rogers in 1994. The observation tested the non-injured leg of ACL-deficient athletes and compared them against subjects who were the same age and sex and who had not suffered an ACL injury. The test concluded that:

Athletes with ACL injuries were found to have greater degrees of navicular drop, suggesting a greater subtalar pronation and greater anterior knee joint laxity. These results suggest that the more an athlete pronates (as well as the greater the knee joint laxity), the greater the association with ACL injury (Griffin et al., 2006, p.1515).

While foot pronation may not be the sole cause of an ACL injury many researchers suggest that such a condition could lead to excessive joint laxity. If both conditions are present in an athlete, the risk of sustaining an ACL injury increases.

Having a narrow intercondylar notch has long been a heavily debated topic in the realm of ACL injury-causing attributes. Using this method to identify injury risk is questionable because it is difficult to obtain the size of the ACL and

the intercondylar notch without direct contact. A typical way of measuring the ACL and the intercondylar notch is by using various imaging techniques that do not touch the ACL, but doing this requires some conjecture (Griffin et al., 2006, p.1516). These techniques are good at getting relative data but lack in obtaining exact measurements that are needed to identify a feasible internal factor.

Some researchers have gone to the expensive length of using a MRI to observe the femoral notch of male and female athletes. One study conducted by Anderson et al. in 2001 revealed that "ACLs in girls were smaller than in boys when normalized for body weight" (as cited by Griffin et al., 2006, p.1516). Another study that used MRI's, conducted by Charlton et al. in 2002 it found "that the volume of the ACL in the femoral notch midsubstance was smaller in women compared with men and that this difference was related to height. In addition, they found subjects with smaller notches also had smaller ACLs" (as cited by Griffin et al., 2006, p.1516). It can be drawn from the two studies that the femoral notch and the ACL of females are smaller and therefore are more susceptible to tearing if put under the same force as a male ACL. However, "[e]ven if an association between notch width and noncontact ACL injury risk is reliably found, the mechanism by which notch width might be related to ACL injury remains speculative (Griffin et al., 2006, p.1517). There is a high probability that the presence of a narrow femoral notch and a small ACL can significantly raise the chance of an injury. But like most internal risk factors, these characteristics are rarely the sole cause of an injury.

One final anatomical contributor to ACL injuries can be found in the athletes' hormones. Researchers have found that "sex hormones have a profound effect on collagen and have been shown to mediate cyclic increases in knee laxity" (Shultz et al., 2007, p. 237). As previously stated, having increased joint laxity can increase the chance of ACL injury. Many laboratory studies have shown that female sex hormones affect the structure and metabolism of the ligament. Hewett states that "studies conducted over the past seven years have lead to important advances in our understanding of the relationship between the cycle phase and ACL injury risk, and have prompted us to think more about the role of hormones as an ACL injury factor" (as cited by Shultz et al., 2007, p. 233). However, it is important to remember that females' menstrual cycles vary from person to person. Before the menstrual cycles' effect on ACL injury can be fully understood, there must new and creative "study designs that can better capture the unique characteristics of each female's menstrual cycle..." (Shultz et al., 2007, p. 233). While the presence of hormones may lead to an increased chance of ACL injury, it would be unethical and ill-advised to alter one's hormones to decrease the chance of an ACL injury.

While race or ethnicity does not fully fall under the category of anatomy, it can play an important role in the frequency of ACL injuries. A study conducted from 1999 to 2003 concluded that "the rate of anterior cruciate ligament tears is different in White European American female basketball players and non-White European American players." The results indicated that White European-

American women tear their ACLs "0.45 per 1000 athletic exposures, whereas for non-White European American players (black or African American, Hispanic, and Asian players) the rate was 0.07" (Trojian & Collins, 2006). The conclusion drawn from the data is that White European-American athletic women are six times more likely to tear their ACL than any other athletic group.

Even being in the same family as someone who has torn their ACL increases one's likelihood for having an ACL injury. This is not surprising because children who have siblings of the same sex tend to have similar body types. A retrospective study completed by Harner et al. in 1994 examined 31 patients who had sustained an ACL injury. These individuals were matched with 23 other subjects who had analogous age, height, sex, and activity level. The study concluded that "[eleven] of 31 patients who sustained bilateral injuries had a family history of ACL injury (35%)" (as cited in Griffin et al., 2006, p. 1520). In comparison, only one of the twenty-three control subjects, whose family had no incidence of knee injuries, suffered an ACL injury. Another, more recent study conducted by Flynn discovered that patients with ACL tears were "twice as likely to have a relative (first, second, or third degree) with an ACL tear than compared to participants without an ACL tear" (as cited by Griffin et al., 2006, p. 1520). While siblings do share common physical characteristics, it is not a guarantee that family relation will significantly increase the chance of another sibling sustaining an injury. However, joint laxity and hereditary knee injury cannot be corrected through physical training.

There is no definite way to look at an individual and be able to tell if he or she is susceptible to an ACL tear. It is only after the athlete has been viewed in numerous athletic situations that some of the anatomical internal factors become apparent. Other anatomical factors, such as the intercondylar notch and hormones, are more difficult to identify. While they can play a large role in making an individual more susceptible to injury, more research must be done before they can be used for injury prevention purposes. Finally, no person can change the way that they are structurally assembled, the amount of hormones their body naturally produces, or even their inherited ethnicity. The anatomical internal factors serve as a tool to inform an athlete of their physical attributes that increase their likelihood of suffering an ACL injury. Once an athlete identifies his or her own anatomical risk factors, it is up to him or her to choose the strength and conditioning program that decreases the chance of injury.

### **2.3.3 Neuromuscular Factors**

“Neuromuscular factors include reaction time, motor unit recruitment, and balance (coordination)” (Griffin et al., 2006, p.1521). These qualities give athletes a distinct advantage in agility and quickness. The brain informs the body to assume the most appropriate physical position given the athletic situation. When done correctly and quickly, the body can output at its highest efficiency and avoid noncontact injuries. When the connection is slow or ineffective, the

body's joints struggle due to the large amounts of force that are transferred to small ligaments instead of major muscle groups.

Multiple controlled laboratory studies conducted by Bahr and Krosshaug have consistently shown that:

Women, compared with men, appear to land a jump, cut, and pivot with less knee and hip flexion, increased knee valgus, increased internal rotation of the hip, increased external rotation of the tibia, ....., and high quadriceps activity relative to hamstring activity, that is, quadriceps-dominant contraction (as cited by Griffin et al., 2006, p.1528).

Landing and cutting with decreased knee and hip flexion transfers the force of the ground pushing back against the legs directly to the joints instead of the muscles. Most athletic instructors advise that playing in a low, knee bent, athletic stance is advantageous because it transfers force to bigger, stronger muscles that can take more force and repair themselves more easily if damaged.

Researchers Ireland and Olsen state that increased "functional valgus collapse" and increased internal hip rotation not only puts the medial and internal ligaments of knee under additional stress, but it can also lead to increased joint laxity. These factors greatly contribute to an overall decrease in knee joint stiffness (as cited by Shultz et al., 2007, p. 251).

Decreased joint stiffness or joint laxity is a problem because it allows the joint to move in directions that can cause ligament damage. A study conducted on 1200 military cadets concluded that "[w]omen with knee laxity values that

were [slightly greater than the accumulated average] had a 2.7 times higher relative risk of injury than did women with lower knee laxity values." The study also implied that anterior knee laxity is a potential ACL injury risk factor the study as a whole, but it is unsure that the number of ACL tears were caused by anterior knee laxity. Therefore, it is difficult derive any definite conclusions from the small amount of ACL injured individuals (as cited by Griffin et al., 2006, p. 1518).

Having high quadriceps activity relative to hamstring activity is dangerous to an athlete because it puts his or her knee-controlling muscles out of balance. One of the most common ways that the ACL is torn is through excessive anterior tibial translation. The quadriceps act as the agonist, pulling the patella and the tibia forwards, placing the tibia in a position where it is parallel to the femur. The hamstrings act as the antagonist, pulling the tibia posteriorly, opposing the forces that the quadriceps place upon the tibia. Meyer stated that the quadriceps are normally stronger and quicker to react than the hamstrings, but when the "...hamstring-to-quadriceps strength ratio [decreases to] less than 55%," the knee becomes unbalanced, thus increasing the likelihood of injury during strenuous athletic activity (as cited by Garrett & Yu, 2007, p. 117). When the brain realizes that the body is in an anatomically dangerous position, it will send signals to the muscles of the at-risk limb to correct its position. If the signal does not arrive quickly enough or if an inadequate number of muscles are fired to correct the dangerous position, the most common outcome is an ACL injury.

The best way to avoid injuries due to lack of motor control or reaction time is to improve the brain's transfer of signals to the muscles. Hewett stated that "there is evidence that neuromuscular training not only decreases the landing forces and increases balance but also decreases ACL injury incidence in females" (Hewett, Myer, Ford, 2007, p.90). The faster the brain can tell the body to get into a correct position, the more likely the athlete will be able to avoid injury. Some conditions like joint laxity cannot be fixed by training. No matter how fast the signals are sent for the muscle to fire, there still will be an abnormal amount of looseness that the muscles have to overcome. In such a situation it is best if the athlete knows the limitations and avoids hazardous movements. As a rule, greater balance and reaction times will lead to improved overall stability. After stability is achieved, strength can be added to help the athlete maintain a correct posture in more extreme or dynamic movements.

#### **2.3.4 Biomechanical Factors**

The topic of ACL tear has long been a topic of interest for the discipline of biomechanics. Biomechanically, a knee injury is caused by two factors, where an athlete's center of gravity is placed and the accuracy of the athletes' skeletal adjustment to the surroundings. It is believed that "(a)nterior cruciate ligament tears are thought to occur with unsuccessful postural adjustments," when strong, abnormal forces are placed upon the knee (Griffin, 2006, p.1520). It is very common in high-impact sports that require large amounts of agility, such as

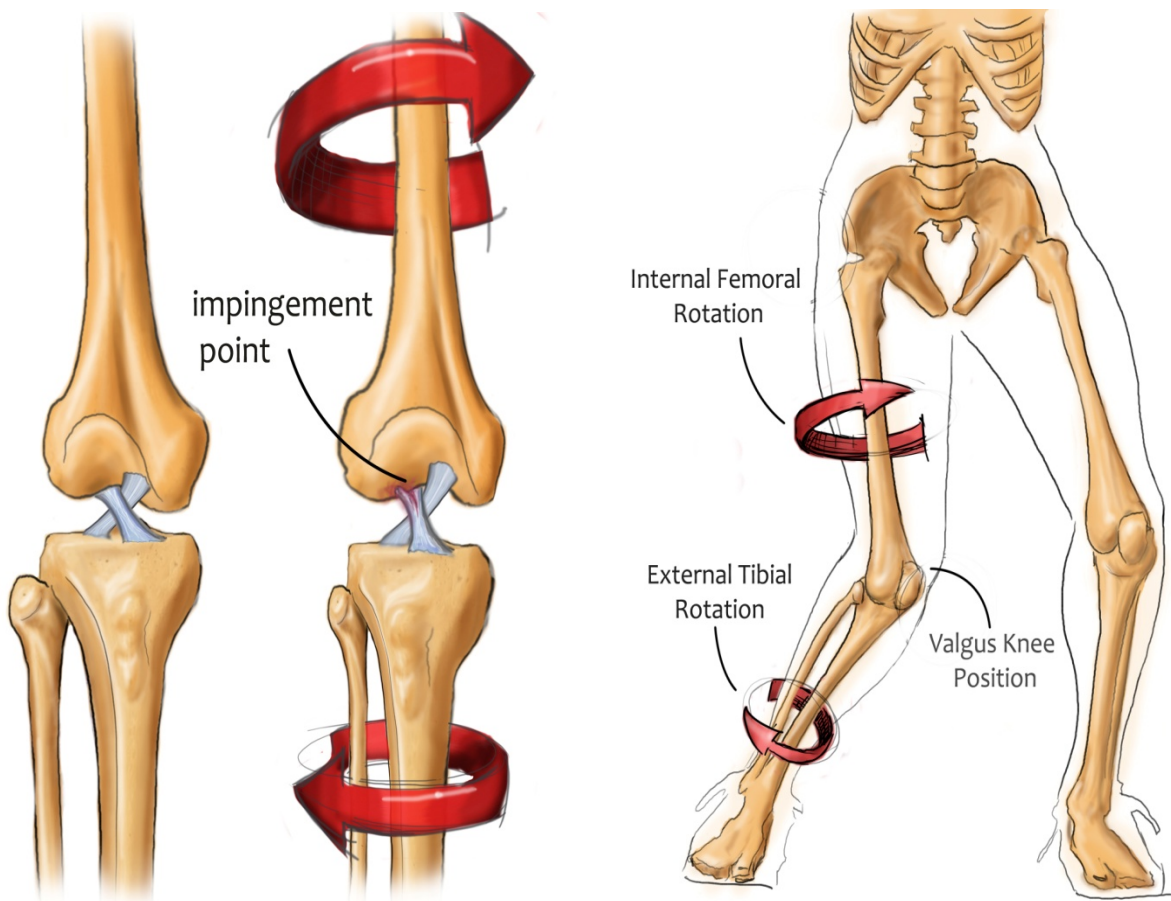


soccer, basketball, and football, that these “unsuccessful postural adjustments” take place.

Some factors that make postural adjustments less successful are “fatigue, decreased torsional stiffness, muscle imbalance, unanticipated cutting, and straight posture on landing (hips and knees near full extension with an upright torso)” (Griffin et al., 2006, p.1520). All of these negative effects can be corrected through increased muscular motor learning. Adjusting the body to be in the correct position for dynamic movement is not only the role of the nervous and skeletal system; the body needs a high level of appropriate muscle function to achieve any task. Different people’s muscles respond and adjust to a range of situations differently. However, there are some positions that the body can assume that reduce muscle activity and in turn increase the chance of an injury. A study conducted by Beynnon and Fleming realized that “[h]igh ACL strain rates were documented with the knee near full extension and with quadriceps or isometric hamstring contraction,” while “[l]ow ACL strain rates were noted with the knee flexed less than 50 degrees and with hamstring or isometric quadriceps contraction” (as cited by Griffin et al., 2006, p.1520) This verifies that assuming a crouched, wide stance can not only allow an athlete to compete more effectively but also aid in injury prevention.

There are two generally accepted biomechanical descriptions of how an ACL tears. The first is described as hyperextension. When an athlete lands from a jump, he or she typically accepts the force of their body weight, rate of fall,

and inertia by bending the knees forward, transferring those forces throughout the muscle bodies of the thighs, calves, and feet. But when hyperextension occurs, the knee goes rearward, causing great stress on the ligaments, especially the ACL and PCL. Although these types of ACL injuries do contribute to the total amount of injuries per year, these injuries are relatively rare. Researchers Krosshaug and Bahr concluded that “[a]lthough some hyperextension injuries are reported in interviews, none were seen in any of the noncontact injuries from the video analysis” (Hewett, 2007, p. 140).



**Illustration 7. “Point of No Return”**

The second and most common way that noncontact ACL injuries occur is during an acceleration or deceleration movement combined with the opposed twisting of the femur and the tibia. Ireland (1999) described this combination of movements as “the point of no return” (as cited by Buchanan, 2004). Weimar has developed a theory for the causation of some ACL injuries. She states that when the knee is bent and the tibia is actively externally rotated, this shuts off two of the three hamstring muscles that prevent the head of the tibia from traversing anteriorly. This leaves the biceps femoris the sole protagonist responsible for negatively accelerating an athlete’s horizontal force. If the hamstring is not strong or quick enough in accepting these forces, it is very common that the head of the tibia will traverse anteriorly to the point where it tears the ACL (Weimar, personal communication, February 20, 2009).

Both anatomical and neuromuscular factors can lead to biomechanical failure, but neither are necessary for a biomechanically defined knee injury. Weimar states “that even if the most impressive physical specimen or most gifted athlete plants and pushes in an incorrect way even once out of 999 exposures, the ligament will tear” (personal communication, September 1, 2009). From the research it is logical to conclude that in most cases there is no one internal factor that leads to an ACL injury. For most ACL injuries, there must be a combination of internal factors present when a biomechanical failure occurs. The best way to prevent knee injury is to identify what elements of an athlete make him or her more susceptible to injury and work to remediate those weaknesses.

## **2.4 External Factors**

While there are many internal factors that an athlete can possess that makes them more susceptible to an ACL tear, there are also some external factors that must be considered. External factors are conditions that exist outside of the physical body of the athlete that can contribute to an ACL injury. Such circumstances are "meteorological conditions, the type of surface (grass, hard floor, etc), the type of footwear and its interaction with the playing surface, and protective equipment such as knee braces" (Griffin et al., 2006, p.1513). The only way to avoid these injuries is to not participate on the field in poor meteorological conditions or be specific in what footwear or bracing system is used during an athletic activity.

### **2.4.1 Meteorological Factors**

In most sports playing scenarios, the ground or surface on which the athletes play upon has to adhere to some standard, be it four bases, a clay court, grassy area, or hard wood floor. Indoor playing arenas tend to stay consistent year round due to being sheltered from the elements, while the composition of most outdoor fields is subject to changing meteorological conditions. Orchard (1999), a researcher that studied Australian football fields, "reported that noncontact ACL injuries were more frequent during high evaporation and low-rainfall periods. The harder ground conditions during these

climatic conditions presumably increase the shoe-surface traction and the risk of ACL injury” (as cited by Griffin et al., 2006, p. 1513). Most organized sports have some system that keeps their field of play in a consistent quality. However, this type of maintenance cannot be applied to all fields of play. The problem with high evaporation and low rainfall is that it leads to playing surfaces that are abnormally firm. This firm ground increases shoe-to-surface traction, thus causing the foot to “stick” on one location when the body needs to pivot to avoid injury. This type of field can also exist in areas that are subject to below freezing temperatures and heavy amounts of rain. When the ground becomes saturated with water, the water freezes, making the ground hard. This sticky, wet, and hard ground increases shoe-to-surface traction that leads to injury.

#### **2.4.2 Footwear and Bracing Factors**

Another contributing external factor that makes field conditions dangerous is the footwear. It was formerly thought that increased cleat length was directly related to the risk of knee and ankle injuries. However, a study conducted by Milburn and Barry stated that “athletes modify their movement patterns to adapt to variations in shoe and surface factors and thereby may alter neuromuscular and biomechanical factors that influence ACL injury risk” (as cited by Griffin et al., 2006, p. 1514). In other words, when the playing surface is abnormal, the players are prone to change their typical style of movements to either take advantage or avoid certain conditions that the playing surface presents them. For

example, athletes who are playing on unusually soft ground will plant at a more horizontal angle to accelerate their change of direction while athletes who are playing on a wet, hard surface will “chop” their feet while decelerating to gain additional traction and avoid falling. While it is more likely that abnormally increased shoe-to-surface traction is a large contributor to ACL injuries, it cannot be dismissed that changing one’s typical movement patterns can either contribute or counteract the elements that lead to an ACL injury.

The use of knee braces for the purpose of preventing ACL injuries have been a heavily debated topic for many years. Many schools that have athletes on scholarship require at-risk athletes to wear a brace for preventative measures. There are very few quality studies that have investigated the role braces play on ACL prevention. One study followed the knees of 1396 cadets playing intramural tackle football at the United States Military Academy. This study “found that prophylactic knee brace use was associated with a reduced rate of knee injury” (Griffin et al., 2006, p. 1514). The study concluded that non-braced cadets were three times more likely to have an ACL injury than braced cadets. Though this conclusion is valid, the study has two flaws. The first is that the study does not denote the types of braces used to prevent a knee injury. The second flaw is the number of ACL injuries recorded was too low to offer a definitive conclusion. The total number of ACL injuries were only 16; 4 were braced, 12 were not (Griffin et al., 2006, p. 1514).

One promising element that some brace manufacturers can deliver to the athlete is that their product can decrease the chance of an ACL injury by limiting the unwanted movements of the limb. Most braces have a hinge that controls the extension and flexion of the limb. This hinge prevents the leg from hyperextending, which is a frequently reported cause of ACL's tear. Another preventative method that some brace manufactures boast is the ability to control the rotation of the tibia. *Townshend Design* claims to control the rotation of the tibia through a bolster and non-migrating, non-stretching, suspension strap (Riley, 2009). *Asterisk*, a designer of motocross knee braces, has a similar approach to correct the rotational issue. The company designed its braces to have an anti-rotational tether that connects the bottom of the brace to the top of the shoe. The thought behind the design is that, if the foot cannot twist, neither will the tibia. While both braces claim to lessen ones' susceptibility to ACL injury, limiting the knee's rotation will in turn affect the leg's range of motion. Doing this will not only lower an athlete's agility but also weaken the stabilizing muscles of the knee, making the athlete even more susceptible to injuries when the brace is not used.

### **2.4.3 Summary of External Factors**

It is important to keep in mind that no matter how physically perfect an athlete is, he or she heightens the chance of a knee injury by exposing him or herself to the aforementioned external risk factors. Playing on a surface that is not ideal will change the way the athlete moves and performs. Typically, performance will decrease or chance of injury will increase; possibly both. A lack of shoe-to-surface traction will make an athlete less agile, but it will probably reduce their chances of sustaining a noncontact knee injury. The athlete has to decide for him or herself how much grip is appropriate to an activity and will not contribute to joint damage during game play. Wearing a brace as a preventative method, at the very least, will give some support and make the joint more stable. Whether a knee brace is able to prevent the tearing of an ACL is still undecided (Beynnon & Slauterbeck, 2007). Regardless, if braces do give additional stability to the joint, they have the potential to decrease the agility, speed, and quickness of an athlete.

### **2.5 Summary of Internal and External Factors**

A noncontact injury can be caused by an anatomical attribute, a neuromuscular attribute, or by an incorrect biomechanical position. While all three can be present at the time of injury, the only factor that is guaranteed to occur at the time of injury is an incorrect biomechanical position. The internal and external factors are elements that increase the possibility that an individual



will sustain an injury. To avoid the internal factors, it is best to discern what areas present the greatest amount risk of injury to the individual athlete. Once this area or areas of risk are identified, it is the athlete's or the athletic trainer's responsibility to ensure the correct training methods are followed. In the case of the college-aged athlete, it is especially important to ensure that the training activities are concise and effective. When elements of external risk factors are present, it is even more important to avoid putting one's self in a potentially dangerous situation. In regards to cleat length and brace use, it is important to use what is appropriate. If the cleat causes too great shoe-to-surface interaction, it should be changed. If the brace does not fit correctly or causes overdependence, then it should be removed. The goal of reviewing the internal and external factors is to identify what characteristics are present and decrease them as efficiently and quickly as possible.

## CHAPTER 3: INTRODUCTION TO PREVENTATIVE PROGRAMS

### 3.1 Overview

There have been many studies done on the causes of ACL injuries; there has also been a great focus on preventative programs. *Understanding and Preventing Noncontact Anterior Cruciate Ligament Injuries* from the American Sports Journal, published in 2006, included a table of twelve preventative programs. This table included the programs' purposes, test group size, outcomes, and other relevant information. Out of the twelve programs, seven focused on a range of activities that trained an athlete's proprioception, agility, strength, flexibility, and plyometrics. Only one program focused solely on ACL tear in male athletes, leaving the remaining six studies to spotlight the female athletic population, which is more susceptible to ACL injuries.

The following graphs were taken from the thirty-fourth volume of the *American Journal of Sports Injury*, where Silvers summarized twelve prevention programs regarding the data presented at the Hunt Valley Meeting (as cited by Griffin et al., 2006, p. 1525-1526). This information is presented in table 4 and 5.

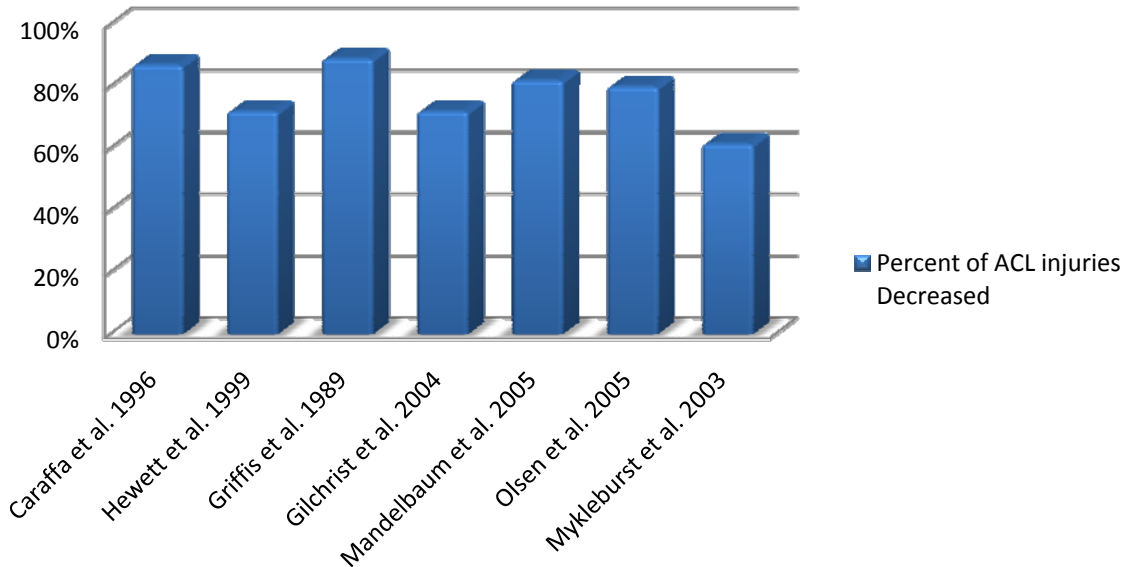
Author	Sport	Number tested	Duration	Sex	Random	Equipment	Strength training	Flexibility Training	Agility Training	Flexibility Training
Griffis et al (1989)	Basketball	not reported, 2 teams	8 years	Female	No	Jump Box, Balance	No	No	Yes	No
Caraffa et al (1999)	Basketball, volleyball, soccer	T, 300 C, 300	3 seasons	Male	No, prospective	B alance Boards	Proprioceptive, neuromuscuair, facilitation exercises	Yes	No	Yes
Hewett er al (1999)	Basketball, volleyball, soccer	1263	1 year	Male/ Female	Yes	Jump Box, balance	Yes	No	No	No
Mykleburst et al (2003)	Team Handball	900	3 years	Female	No	Wobble Board, balance foam mats	No	Yes	Planting neuromuscuair control	Yes
Gilchrist et al (2004)	Soccer	561	1 year	Female	Yes	Cones, Soccer ball	Yes, gluteus medius abduction, extension, hamstrings, core	yes	Deceleration, sport specific	yes
Mandelbaum et al (2005)	Soccer	T, 1041 C, 844	2 years	Female	No, voluntary enrollment	Cones, soccer ball	Hamstrings, core	Yes	Soccer specific with decel.techniqe	Yes
Olsen et al (2005)	Team Handball	18371	1 year	Male/ Female	Yes, cluster randomized controlled trial	Wobble board; balance foam mats	Yes	Yes	Cut, neuromuscular control	Yes

**Table 4. List of Effective ACL Preventative Programs**

Agility Training	Plyometrics	Author	Proprioception	Programs Strengths	Programs Weakness	Outcome
Yes	Landing Technique	Griffis et al (1989)	Deceleration Pattern, (3-step shuffle)	Changing Deceleration and landing techniques	not randomized, unpublished	89% decrease in noncontact ACL injury
No	No	Caraffa et al (1999)	Yes, Balance Board activities	Mechanoreceptor/proprioceptive training	additional equipt.. Not effective on large scale	87% decr. In NC ACL, injury rate reduced to 0.15/1000
No	Yes	Hewett et al (1999)	Yes	Decr. Peak landing forces, decr. Valgus and varus perturbation, incr.	One-to One program in sports facility; not feasible to implement across large cohort	14 ACLs reported; female injury rates 0.43 untrained vs. 0.12 trained vs. male control 0.9 over 6 week program; untrained group 3.6-4.8 higher injury rates of ACL injury
Planting neuromuscular control	Landing Technique	Mykleburst et al (2003)	Balance activities on mats and boards	Compliance to programs monitored, instructional video	Not Randomized	In elite division, risk of injury was reduced among those who completed program, 53.8% and 61.5% reduction of ACL injury
Deceleration, sport specific	landing technique, multiplanar	Gilchrist et al (2004)	Strength onfield perturbation on grass	Instructional video web site, compliance monitored	1 year interventions, began on day 1 of season	Overall 72% reduction of ACL injury, 100% redc. in preactive NC and contact ACL in last 6 weeks of season
Soccer specific with decel. technique	landing technique multiplanar	Mandelbaum et al (2005)	strength onfield perturbation on grass	Instructional Video, Web site; compliance monitored	not randomized; inherent selection bias	injury rates year 1, 88% reduction in NC ACL; year 2, 74% reduction in NC ACL
Cut, neuromuscular control	Landing technique	Olsen et al (2005)	Balance activity on mats and boards	Randomized; compliance monitored, reduction of injury	Efficacious component(s) of intervention not known	129 acute knee and ankle injuries overall; 81 in control (0.9 overall, 0.3 training, 5.3 match) versus 48 injuries in intervention (0.5 overall, 0.2 training, 2.5 match) 80% reduction in ACL

Table 5 . List of Effective ACL Preventative Programs Continued

## Rate of ACL Injury Risk Reduction



**Table 5: Rate of ACL Injury Risk Reduction**

### 3.1.1 Plyometrics

The tables reveal that the programs that are most successful are those that focus on plyometric exercises, agility and balance training, strengthening exercises, and proper technique. Plyometric exercises involve using muscles in the legs and core that control the actions of jumping and landing, the goal of which is to absorb the downward force of the body by means of eccentric contractions (Garrett & Yu, 2007, p. 116). These exercises “enhance joint stability” and aid in injury prevention because they “decrease landing forces, decrease valgus/ varus movements, and increase effective muscle activation” (Griffin et al., 2006, p. 1522). While plyometric exercises are very effective, their rate of success is greater when coupled with other training exercises. One of

these training exercises is agility training; it increases the body's ability to biomechanically position itself, thus avoiding excessive stress on the ACL. This same type of training aids the athlete with managing the unanticipated movements that are also a frequent cause of ACL injury (Griffin et al., 2006, p. 1522).

### **3.1.2 Strength Training**

Strength training is often a byproduct of plyometrics and agility training. One prevention program conducted by Myclebust (2003) did not include a strengthening regiment but still had favorable results because "the plyometric exercises themselves can lead to a strength increase" (Garrett & Yu, 2007, p. 116). Another advantage that strength exercises grant an athlete is that they not only "[improve] quality of muscle function" (Griffin et al., 2006, p. 1522)" but they also allow the muscles in the leg to absorb "greater injurious forces" (Shultz, 2007, p. 100). Lack of strength in the hamstrings makes the quadriceps-to-hamstring ratio a large contributor to ACL injuries. Simply improving the strength of the hamstring lowers an athlete's risk for injury. When using a strengthening routine that emphasizes deep knee flexion, the athlete is able to "decrease the ability of the quadriceps to load the ACL, increase the ability of the hamstrings to unload the ACL, and improve hamstring contraction" (Garrett & Yu, 2007, p. 117). A final benefit to note is that by increasing the strength of the legs, the athlete is less likely to be affected by fatigue. Fatigue during game play

not only leads to a lack of concentration but also a decline of technique while competing.

### **3.1.3 Correct Technique**

As an overarching theme in any sport, the constant improvement upon technique should be encouraged. In order to correct issues like ligament dominance when landing, "athletes should be shown proper athletic position with knees comfortably flexed, shoulders back... and feet approximately shoulder width apart, chest over the knees, and body mass balanced over the balls of the feet" (Garrett & Yu, 2007, p. 116). Creating a prevention program that emphasizes certain techniques "that optimize performance and motor patterns that decrease the risk of injury" (Garrett & Yu, 2007, p. 115) should be the goal of any coach, athlete, or athletic trainer. Even if an athlete could gain perfection in the areas of balance, agility, and strength training, he or she would still be at an athletic disadvantage due to lack of technique. On the other hand, having correct technique is only attainable if there is a sufficient amount of balance and muscular control of the body. When these foundational attributes are obtained, one's athletic ability can only be improved with the increase of muscular and balance training.

### **3.1.4 Summary of Preventative Programs**

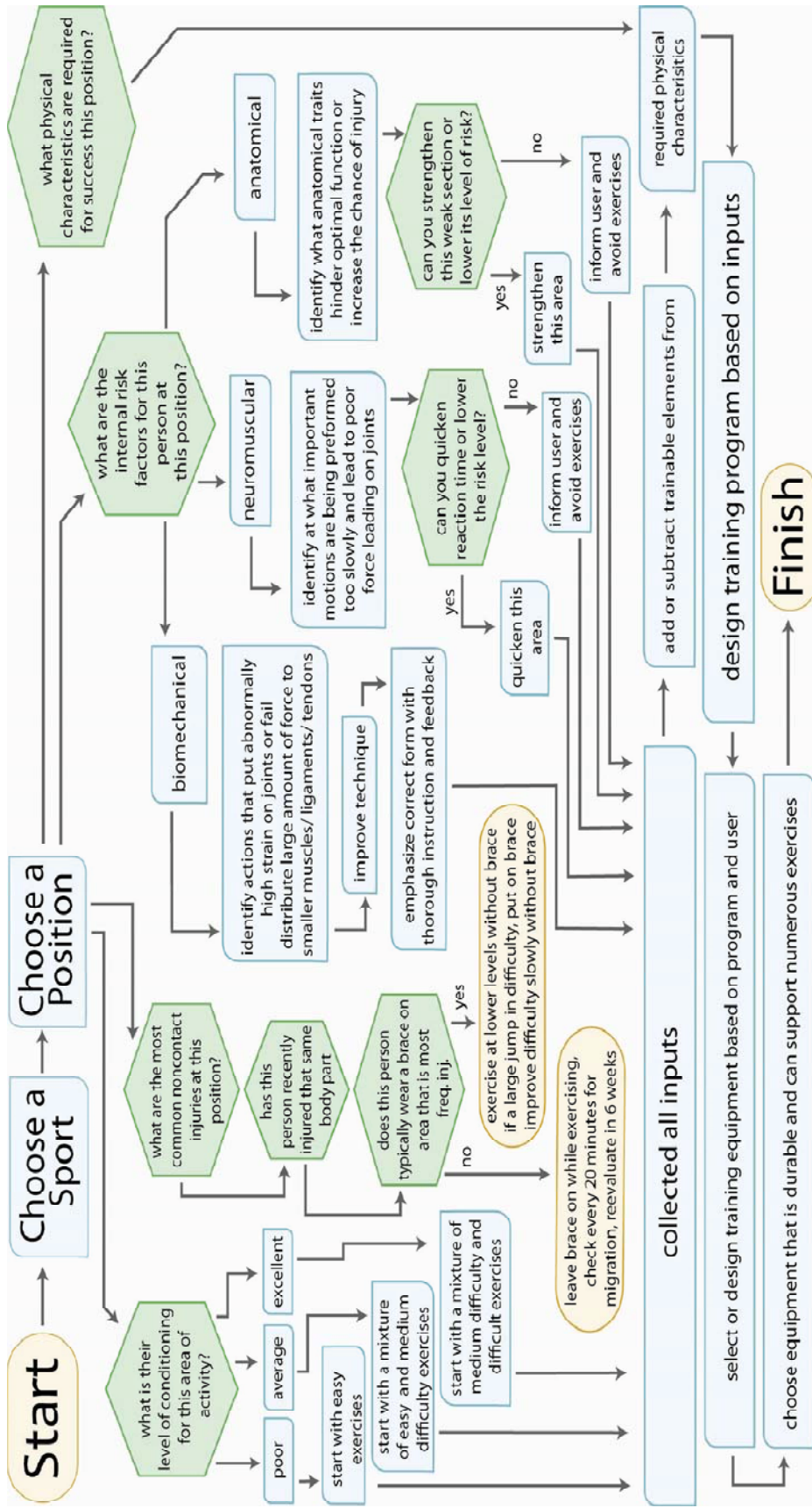
Not all prevention programs that feature plyometrics, balance, and strength training have been successful. The programs that showed the most success had a large and consistent involvement rate of athletes who performed the exercises at the beginning of a season and typically had instructors to show correct form. The teaching technique must be applied in any preventative program; technique allows the athlete to perform at the greatest capacity with the smallest amount of strain on the body. But once sufficient technique is acquired, plyometrics can be used to build strength and agility. A proficient level of balance must be achieved first to control the jumping and landing movements. After that, the explosive nature of jumping, landing, accelerating, and decelerating will lead to muscle growth. Lastly, strength training will allow the athlete to push his or her body to greater limits while adding durability to the body.



## CHAPTER 4: DESIGN DEVELOPMENT

### 4.1 Overview

This chapter will focus on the design and development of an athletic training device that incorporates the exercises that are proven to lessen the risk of ACL injury. A design method has been developed to guide the creation of this device. It includes creating an exercise program by combining the users' preferred sport and position, their internal factors, and their physical conditioning. These inputs will adhere to the created training program in hopes of decreasing the users' susceptibility to noncontact injuries. Once the criteria for the training program have been established, a design process consisting of ideation, preliminary sketching, professional review, refinement sketching will take place. The final product will be refined in such a way that decreases packaging size and optimizes the use of multiple exercises to the fewest amounts of training devices. The sketches will be reviewed by designers for quality and feasibility of design, brand cohesion, and effective use of space. The sketches will also be reviewed by biomechanists for validation of biomechanical function.



**Illustration 8: Design Method**

*Method for creating an exercise program and training equipment that aids in the prevention of noncontact injuries.*

## 4.2 The Design Method

The design method is intended to direct a designer to create an athletic training program and consequently athletic training devices for the prevention of noncontact injuries. The method starts out with the selection of a sport. The sports that are most applicable to this system are ones that require a high level of agility. After the sport is selected, the individual position is chosen.

From the chosen position, there are four fields in which questions need to be answered. The first is the question of conditioning. Certain positions require more endurance while other positions require more strength and balance. The user will undergo a conditioning test to assess their level of athleticism for the position that they have chosen. The achieved level of conditioning will directly affect the starting degree of difficulty the athlete can access. Achieving a higher level of conditioning will allow the user to attempt more advanced exercises in the training program, earlier.

The second question that must be answered is what noncontact injuries are most common at the chosen position? From this point two more questions are derived. The first asks whether the user has recently sustained an injury to the body part that is the most frequent site of noncontact injuries. If not, this part of the method terminates. If so, it is recommended that the user wear a brace during activity and check it every twenty minutes to prevent migration. After six weeks of training, the user should be reevaluated for improvement and possible removal of the brace. The second question asks if the user has worn a

brace over the frequently injured area for an extended period of time. If not, this part of the method terminates. If so, it is advised that the user take off the brace while performing easier exercises and wear it during more advanced ones. The goal is to strengthen the limb and joint area slowly to avoid building a dependency on the brace when performing advanced athletic movements.

The third question inquires about the user's internal risk factors. These internal risk factors break down into three categories, the first being the area of anatomical risk factors. Anatomical risk factors are any attributes that a person possesses that puts him or her at a distinct structural disadvantage to perform the chosen activity. This category can be very broad. It can range from weak muscles, lax joints, to connection angles of bones that provide less than optimal bone-to-bone contact for structural support. Once the risk factors are identified, the program designer must decide if the risk can be reduced by the training and strengthening of muscles. If the muscles can be strengthened, this will be a large focus of the training program, but it should not become the sole area of focus. Doing so will prevent the user from becoming a physically well-rounded athlete. If the risk factor cannot be reduced, it is necessary to inform the user why he or she will be avoiding exercises that could potentially lead to injury.

The second category of internal risk factors is known as neurological risk factors. These can be identified by one's ability or inability to adjust into the most appropriate physical position in the shortest time as possible. When this does not happen quickly enough, there are typically one or two situations that

are at fault. The first is that the brain does not understand how it needs to orient the body to accept a load until it is too late. The other is that the brain quickly understands what task it needs to accomplish and instructs the muscle to do so, but it takes too long for the muscle activate and move the at risk body part. This can be caused by having lax muscle or tendon fibers. The extra slack takes longer to retract, thus delaying the motion of the body part. Once the risk factors are identified, it has to be decided if the risk can be reduced by the training and quickening of the interaction between the brain and the muscles. If the risk factor cannot be reduced, it is necessary to inform the user why he or she will be avoiding exercises that could potentially lead to injury.

The third and final category is known as biomechanical factors. At the foundation of any noncontact injury, there is a biomechanical failure. It can be caused by an anatomical risk factor, a neuromuscular failure, both, or neither. Biomechanical risk can be identified through the use of poor athletic technique when competing in a chosen sport at a chosen position. Any combination of movements that place an abnormally large amount of stress on one part of the body will lead to injury. For this reason, it is integral that the user be critiqued on form so that he or she will disperse the force generated through athletic activity evenly through the active body parts. Giving thorough instructions on how an exercise is performed and analyzing the athlete's movements throughout the exercise should be an important part of the training program.

The final question is what physical attributes are required to be successful at this position? All the information derived from the first three questions will be added or subtracted from the ideal physical attributes that are required to be successful at the desired position.

All the answers to the previous questions will go into the creation of the training program. They will serve as a guideline on what body parts need to be trained for a specific sport and position. They will illuminate not only what exercises need to be performed but also the equipment to be used. After the training program has been established and the equipment chosen, it is the role of the designer to simplify the system. This is done by making it fold down to a small packaging size, maximizing the amount of exercises that can be done on one portion of the training device.

#### **4.3 Application to Sport, Position, and Athlete**

To give a better understanding of how the method works, the questions from the method will be applied to a hypothetical athlete who is at risk for a noncontact ACL injury. The hypothetical athlete chose the sport of football and the position of cornerback. The first question to be answered is what is his or her level of conditioning? The athlete performed a fitness test developed by *P90X* (The Fit Test) that was modified to measure the conditioning of the lower body and core. The athlete achieved an intermediate to an advanced level of fitness

and will be allowed to attempt intermediate to advanced level training challenges.

The next set of questions that need to be answered is where are most of the noncontact injuries located for the chosen position? For the sport of football and position of cornerback, the most frequent noncontact injuries are sprains and strains in the legs, more specifically the knees and the ankles. One of these types of sprains to the knee is frequently known as a noncontact ACL injury. The following question is does the hypothetical athlete wear a brace on the identified area that frequently sustains injury? The athlete did not wear a brace, so the outcome will not factor into the exercise program.

The next step is to identify what internal risk factors the athlete might have. The anatomical factors that the athlete had were weak hamstrings, an ethnicity that showed elevated injury risk, a history of family knee injury, and some joint laxity. The second set of factors to be identified was the neuromuscular factors. In this area the athlete registered an average reaction time and relatively good balance. Biomechanically, the athlete displays exceptional form in most of his or her exercises with the exception of negative acceleration. The athlete's ability to slow down and change direction could use some work.

The final task to complete is to take the information gathered and add it or subtract it from the required position attributes. For the position of cornerback, strength, quickness and agility from the legs are of the utmost

importance. They need strength to be able to keep their balance when fighting for position against wide receivers.

Cornerbacks need a high level of strength in their legs so it is necessary to train with the purpose of increasing strength. Because the hypothetical athlete is lacking in hamstring strength, the program will be altered to correct this weakness. There is nothing to be done about the ethnicity other than inform the athlete of their elevated risk. The same is true about the presence of hereditary knee injury. The effects of joint laxity cannot be reversed; the best thing to do for the athlete is to strengthen the muscles around the joint and avoid movements that cause the tibia to traverse anteriorly.

#### **4.3.1 Neuromuscular Corrections**

The typical cornerback needs to be quick to realize specific game situations and quicker still to react to those situations. The hypothetical athlete's reaction time is only average, when the typical cornerback's reaction time should be exceptional. The training program will need to push the athlete to get him or her to the necessary level of competitiveness. However, the athlete will start out at an intermediate level of training until the reaction time improves.

#### **4.3.2. Biomechanical Corrections**

The final internal factors to be addressed are those that are biomechanically specific. This largely regards the form and technique the athlete



uses to perform a task. Good technique is essential to avoiding injury and performing at the highest level of athleticism. The only technique-based problem that the athlete displayed was in rapid negative acceleration. Rapid change in direction is absolutely necessary to a cornerback. The training program would like to get the athlete to achieve an advanced level of agility and balance. However, because of the presence of joint laxity, it would be dangerous to put the athlete in an exercise where the tibia could traverse anteriorly. The presence of this internal anatomical risk factor will cause the training program to only permit intermediate level exercises.

#### **4.4 Using Training Program to Create Training Equipment**

In order to design the correct training equipment from the exercise program, the designer needs to choose what equipment can be used to strengthen the athlete and prepare them for athletic competition. The equipment needs to be able to replicate movements that would be performed in game-like situations. Once the appropriate equipment has been designed or selected, the training program can be adjusted to fit an individual athlete's internal risk factors, brace use, and conditioning.

Plyometric training is very good for building strength in the quadriceps and hamstrings as well as developing explosiveness from an athletic position. Incorporating a jump box (see Illustration 9) into the exercise program will be a great way to incorporate plyometric training because of its simplicity and multiple

applications to other types of athletic training. Strengthening the hamstrings of the athlete is also a large concern. To do so, the training equipment will incorporate resistance band training so hamstring curls can be performed.

In the area of neuromuscular training, reaction time, agility, and balance need to be tested and improved. A Bosu ball (see Illustration 10) is a device that is regularly used in physical rehab on patients that need to regain their sense of balance and strengthen the muscles surrounding a joint. It is logical to use this device in the training system, not only because of its common use to train or retrain balance, but also because it adapts easily to a variety of different exercises such as core and upper body strengthening.

Attributes like agility and quickness are difficult to train on only one training device. The use of cones and agility ladders (see Illustration 11) are commonly used in many high agility activities to train the athlete to be quick on his or her feet. These items need to be incorporated in the training device because of their simplicity, their history in agility training, and because of the small amount of space that they occupy.

The use of proper technique is essential to maximizing the output of any athlete. In most situations, correct technique is first introduced to an athlete by an instructor, typically a coach or a more experienced player. After the athlete understands the concept of correct technique it is the role of both the instructor and the participating athlete to ensure that the technique is being practiced correctly. An issue arises when the athlete is not taught correct technique or

once he or she makes an incorrect alteration to their technique. A system or device needs to be created that would allow an athlete to perform their playing technique and receive correction in real time without the constant presence of a certified instructor.

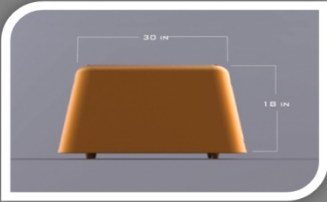
A wide variety of exercises need to be performed on the training device. However, the amount of exercises included in the training program can be very limited based on the inputs that the user provides. For the hypothetical athlete and training program, there is a list of potential exercises that can be performed on the training device. For each exercise there is a brief description of how the device is to be used, what correct form looks like, and the difficulty level with which the athlete will begin.

## Jump Box

— **Good Form:** Being Quiet, Dorsi flexion, feet under hips, trunk in the upright position, don't get too repetitive

<p><b>Easy:</b> Up, up, down, down Up, up, down, down: laterally Up, on top together, down: Reverse</p>	<p><b>Hard:</b> One Legged Jump onto box One legged land</p>
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**Medium:**  
Box Jumps - E and C controlled  
Depth Jumps - get off step, get back on another quickly  
Step up jumps, (while in air change legs)  
Land and Jumps



The diagram shows a trapezoidal jump box with a top width of 30 inches and a height of 18 inches. The box is orange and sits on a grey base.

### **Illustration 9: Jump Box and Exercises**

*The athlete will train on the jump box at "hard" difficulty to strengthen the muscles around the joint.*

# Bosu Ball

– **Good Form:** holding still, keeping joints and limbs stable underneath body

**Easy:**

Crunches, Single Knee Lift  
Calf Raises, Squat (Upside Down),  
Squat Tight side up, Push Ups-  
Switch Hand placement

**Medium:**

Lunges, Back Extension, “V” Sit, Single  
Leg Lift  
Leg Behind on Ball Lunges, One Legged  
Squat  
(Use Upside Down), Plank, Bike,  
Side To Side Lunges

**Hard:**

One Legged Squat Jump , Power  
Lunges, Leg Out Squat, Knelt,  
Left hand and foot down



## Illustration 10: Bosu ball

*Bosu ball at "hard" difficulty to encourage muscle growth around the joint and to gain additional balance.*

# Ladder

– **Good Form:** Always land softly on the balls of your feet when stepping or hopping. Start slowly and learn your patterns before increasing the speed of the drill.

**Easy:**

Lateral Hurdle Hops, Slalom Agility,  
Lateral Shuffle Agility Drill, Ankle Hops  
2 In 2 Out Shuffle , Ali Shuffle, High  
Knees, Lateral Shuffle

**Medium:**

Lateral Plyometric Jumps, Bounds, Single Leg  
Ankle Hop, Skater Hops, Carioca Step (2 Feet  
In), Ickey Shuffle, Single Hurdle Jumps, Slalom  
Agility, Scissor Hops, Backward 2 In 2 Out  
Shuffle, Carioca Step w/ Agility Ladder (1 Foot In)

**Hard:**

Single Leg Cross Hop,  
Lateral 2 In 2 Out



## Illustration 11: Agility Ladder

*The athlete will train at "medium" difficulty because of the athlete's intermediate reaction time; the goal will be to progress the athlete to "hard" difficulty.*

# Resistance Bands

– **Good Form:** Strong Jump, Soft Landing, Knees and Ankles aligned over toes

**Easy:**  
Stationary Running, Calf Raises

**Hard:**  
Vertical Leaping, Box Jumping, Drive to 4 corners

**Medium:**  
Add difficulty to Bosu, Lunges, Small ladder drill



## Illustration 12: Resistance Band Training

*The athlete will train at "hard" difficulty because of the lack of risk from internal factors and the required physical attributes for the position.*

# Four Corners

– **Good Form:** Good athletic posture, straight lines, in and out of crouch, accelerate and decelerate, plant outside, redirect in a straight line

**Easy:**  
Basic mobility, stay low, touch all corners

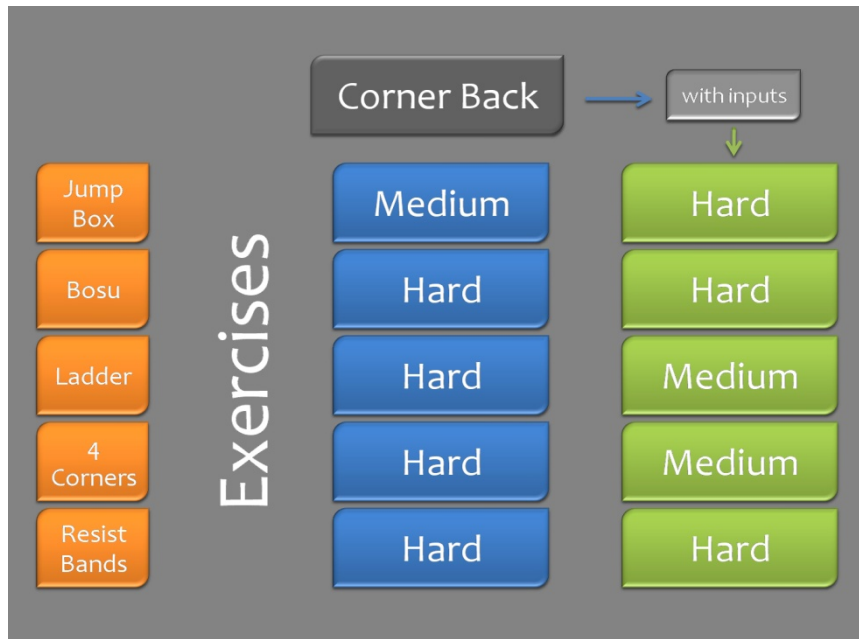
**Hard:**  
Mirror, Color Recognition, Always chopping feet, "L" Drill, Inverted Triangle

**Medium:**  
3 Cone Drill (L Drill), Traditional Four Corners



## Illustration 13: Four Corner Type Drills

*The athlete will train at "medium" difficulty because of poor negative deceleration form and to avoid a potential internal factor.*

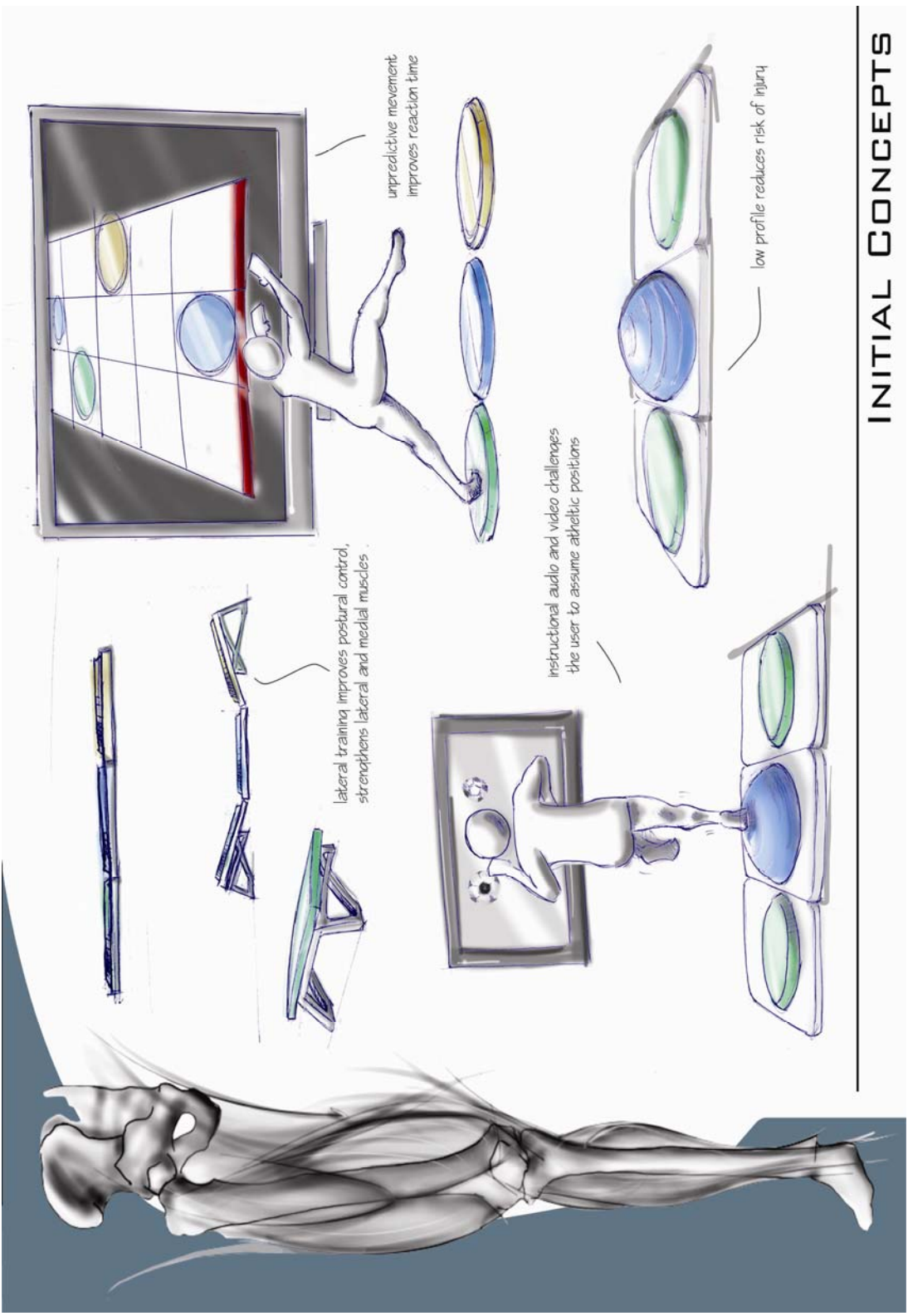


**Illustration 14: Program Changes Based on Inputs**

*A recap of the ideal physical requirements for the position of cornerback that were altered based on the given inputs.*

#### **4.5 Initial Concept Sketches**

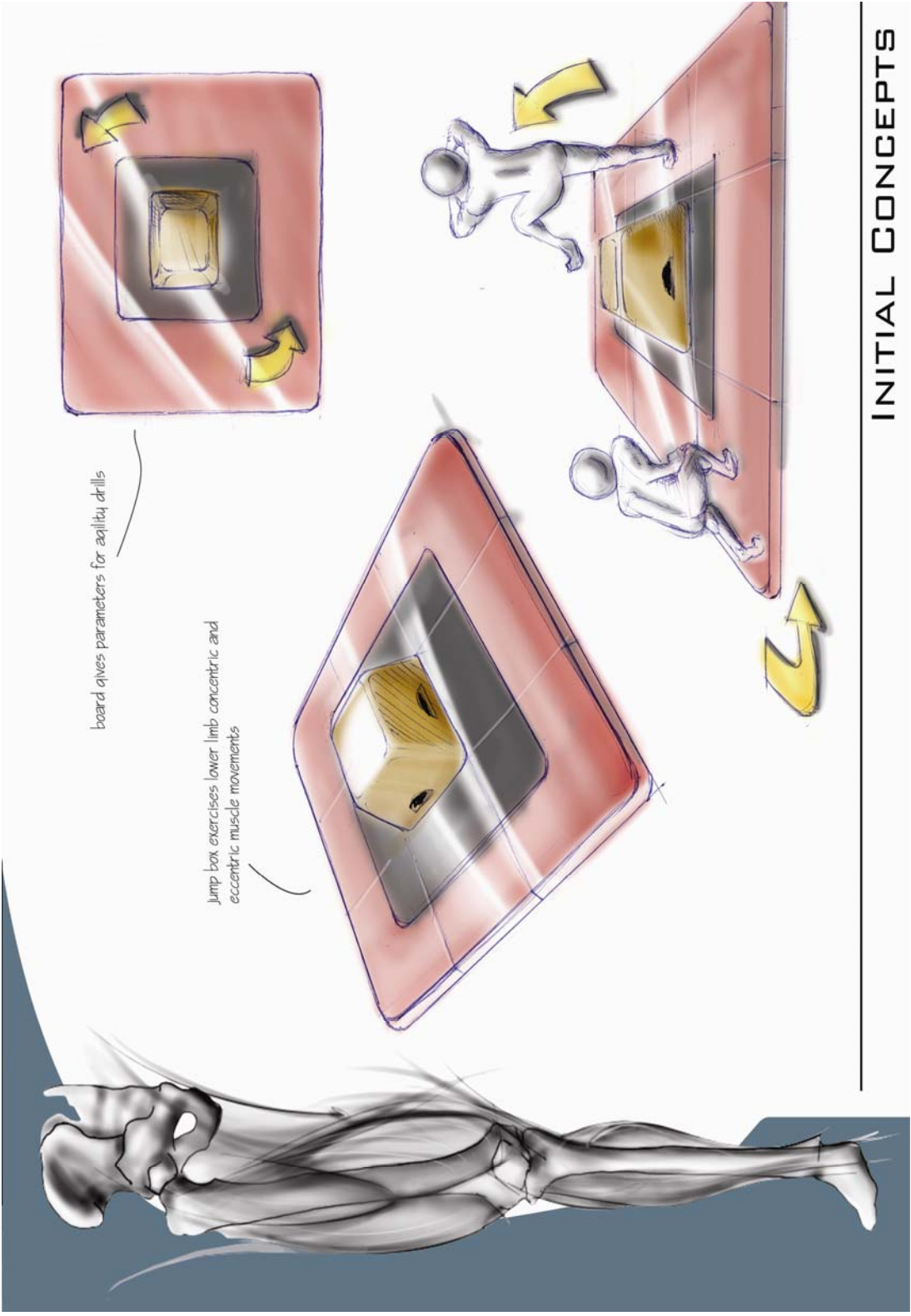
The goal of the training device is to incorporate the exercises that are proven to lessen the risk of ACL injury and achieve an effective use of space for those exercises. The development of preliminary sketches began with the identification of the prescribed exercises and potential training devices. These sketches explore how an individual can reduce the risk to their lower limb by resistance training (see Illustration 4), balance or agility training (see Illustrations 1 and 2), and technique-specific exercises (see Illustrations 3 and 5). The training device will also need to incorporate an instructional training video or interactive game that issues challenges to the athlete to improve his or her balance, strength and agility by following specific tasks or exercises. Visual and audio feedback from the training device will inform the user if he or she is using correct or incorrect form (see Illustrations 1 and 3). Lastly, the device will also need to monitor various points of the body in real time to identify correct form, incorrect form and dangerous movements while being nonintrusive to an athlete's normal range of motion (see Illustration 5).



**INITIAL CONCEPTS**

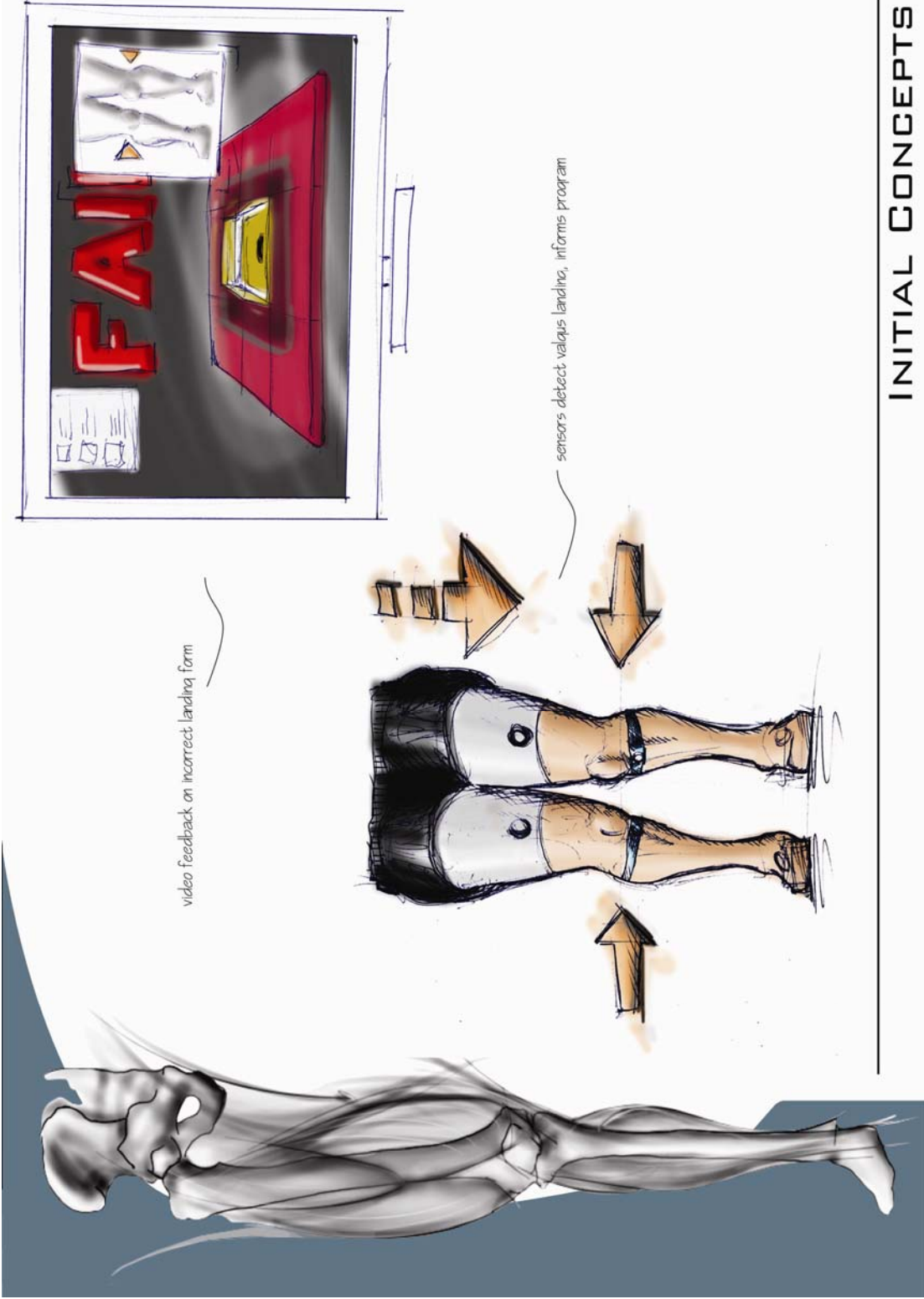
**Illustration 15: Preliminary Sketch 1**





INITIAL CONCEPTS

Illustration 16: Preliminary Sketch 2



**Illustration 17: Preliminary Sketch 3**

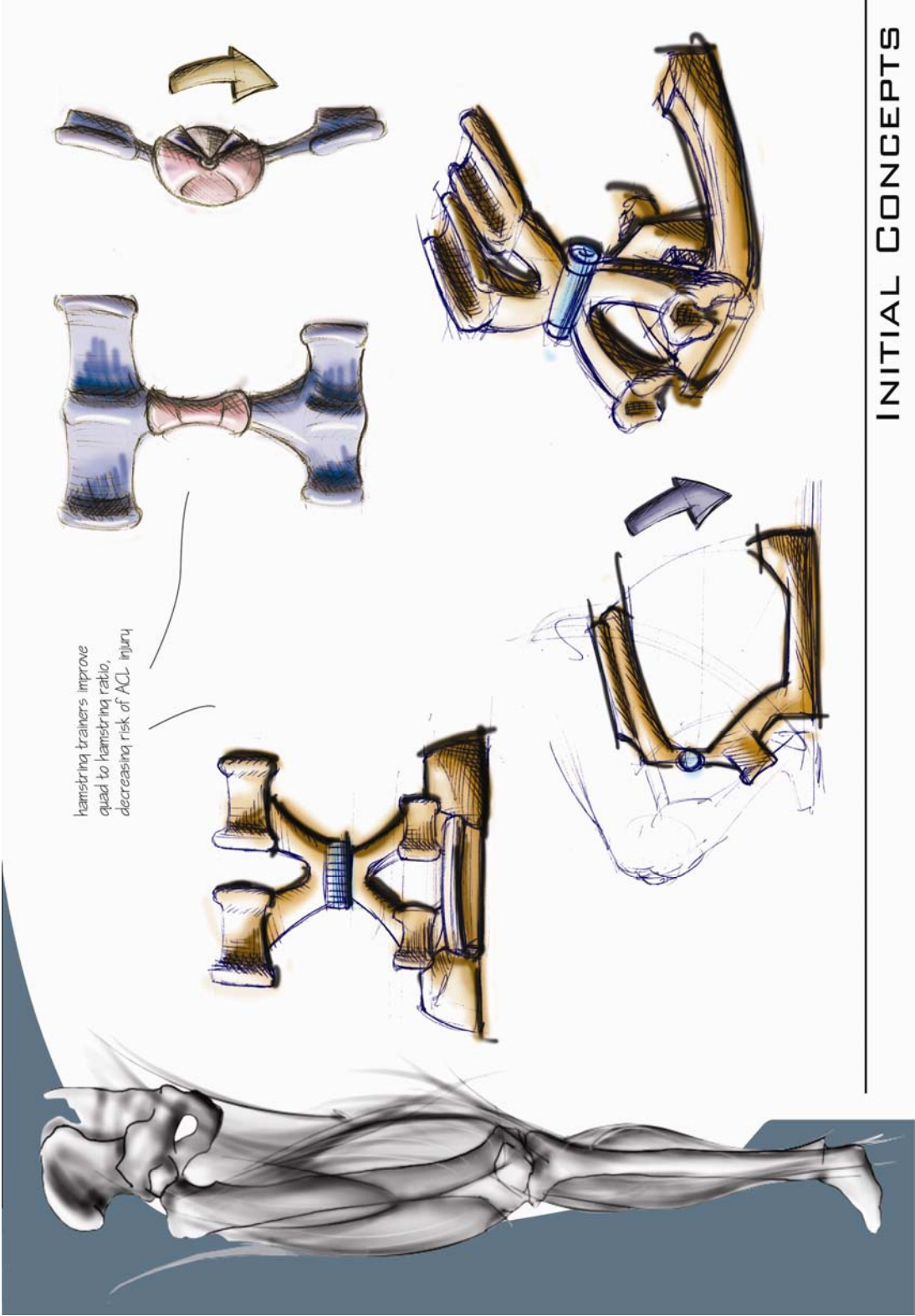
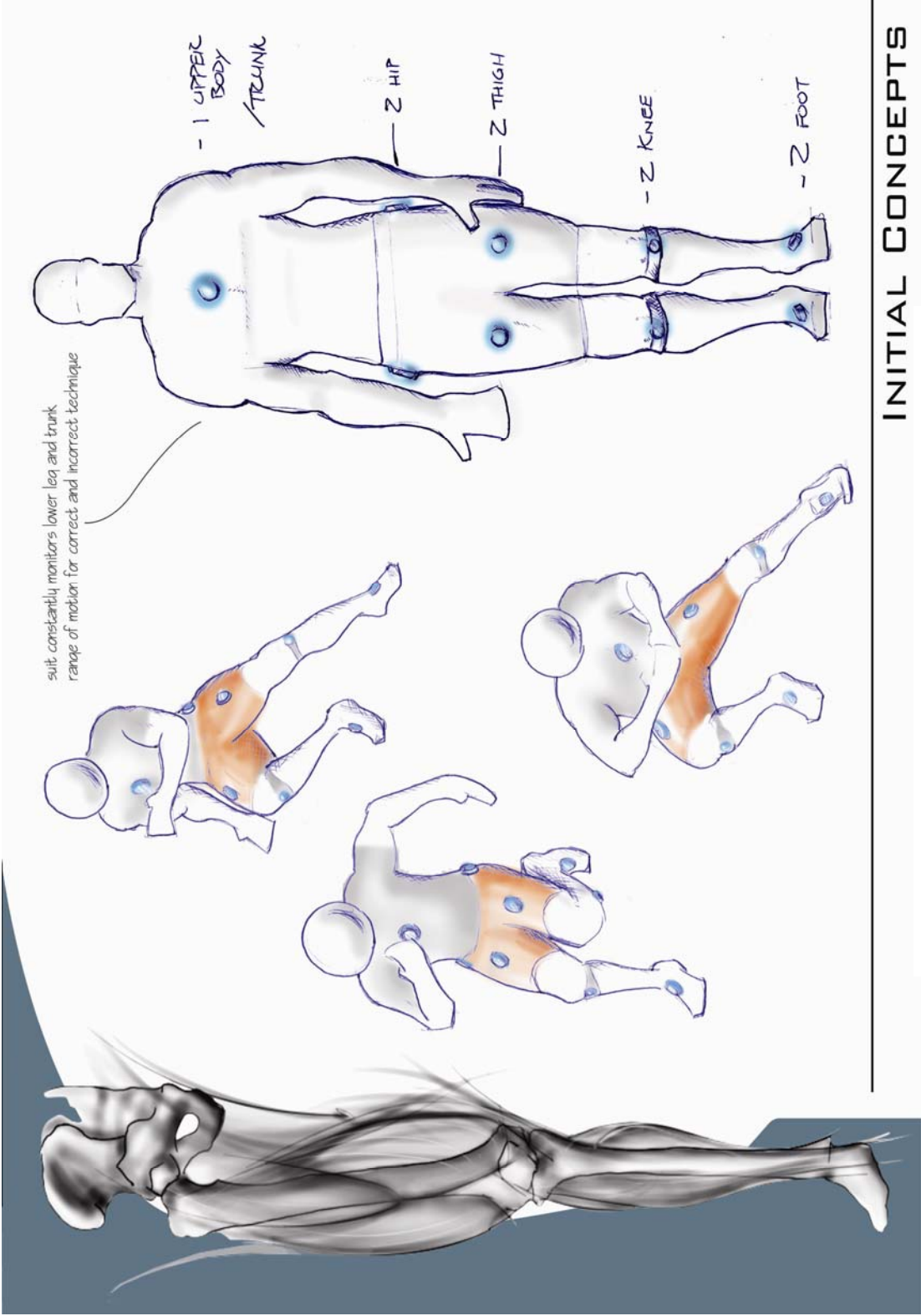


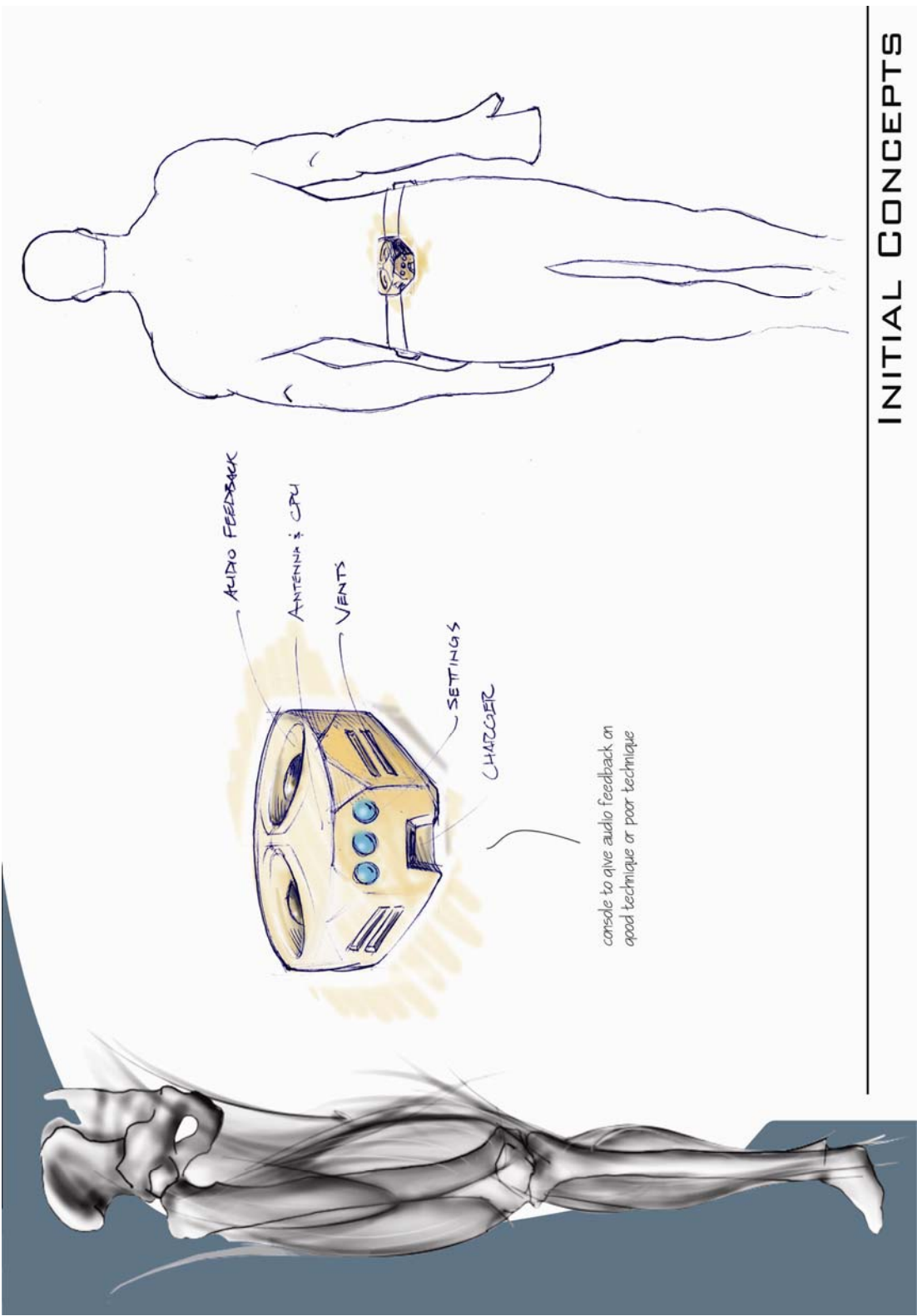
Illustration 18: Preliminary Sketch 4



INITIAL CONCEPTS

Illustration 19: Preliminary Sketch 5





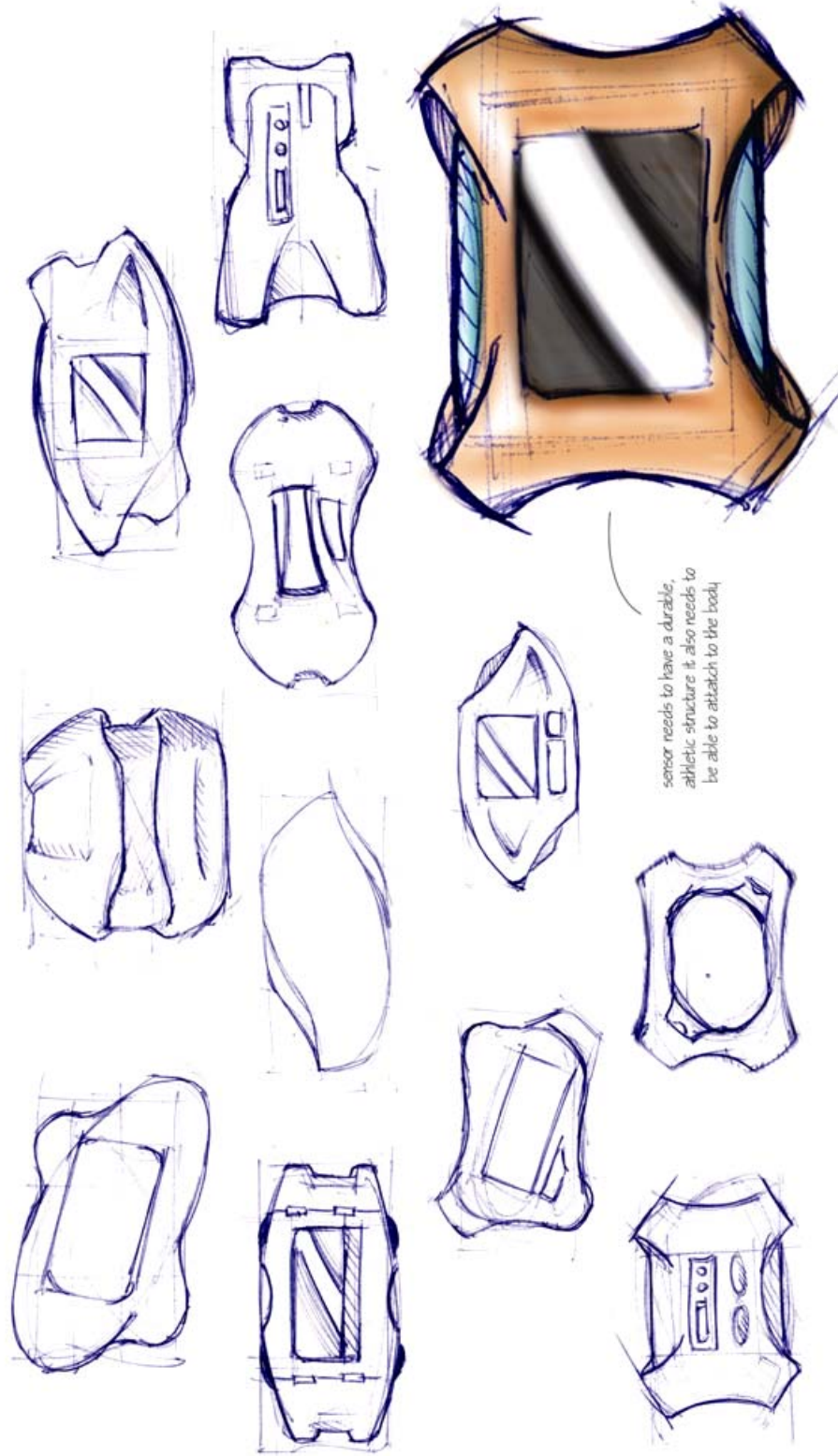
INITIAL CONCEPTS

Illustration 20: Preliminary Sketch 6

## 4.6 Concept Refinements

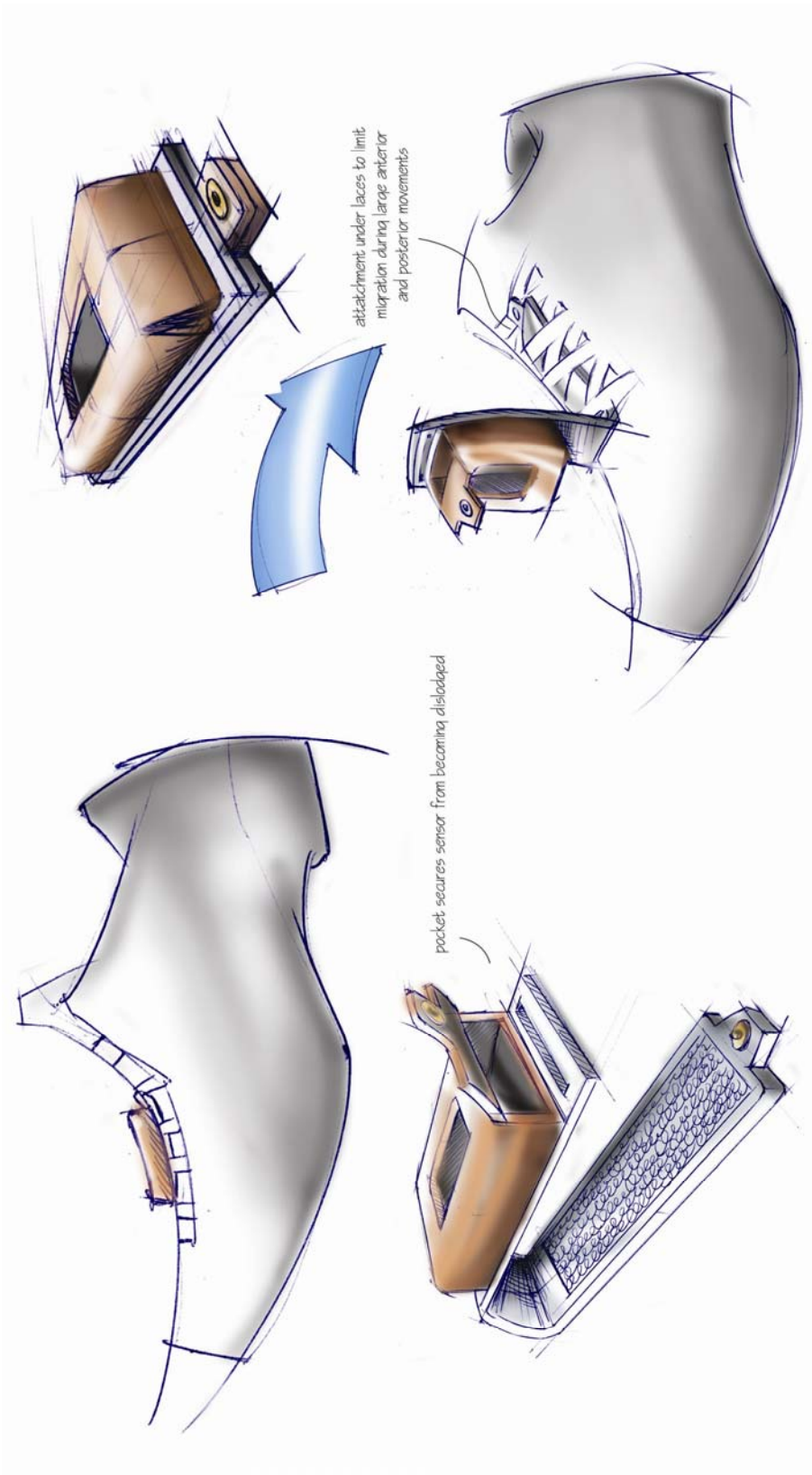
The designs were reviewed by industrial designers and biomechanists. The information they provided helped to eliminate some concepts as well as confirm the potential of other designs. Their observations provided areas for further development. Some of their comments were:

- Focus on plyometrics.
- Examine what exercises the muscle-strengthening devices perform.
- Bosu ball (domed surface) is good for balance training.
- Continue to put user in unpredictable situations through visual/audio input.
- Look at breakdown and packaging side of training module.
- Think about marketability, create a brand.
  - Make a line of training equipment that looks like the pieces belong to the whole, give the system a look of continuity
- Refine and develop the assembly, durability and functionality of the training surface.
- Define how the sensors are attached to the body.
- Discover a new way to train the hamstring.



**Illustration 21: Refined Sketch 1**

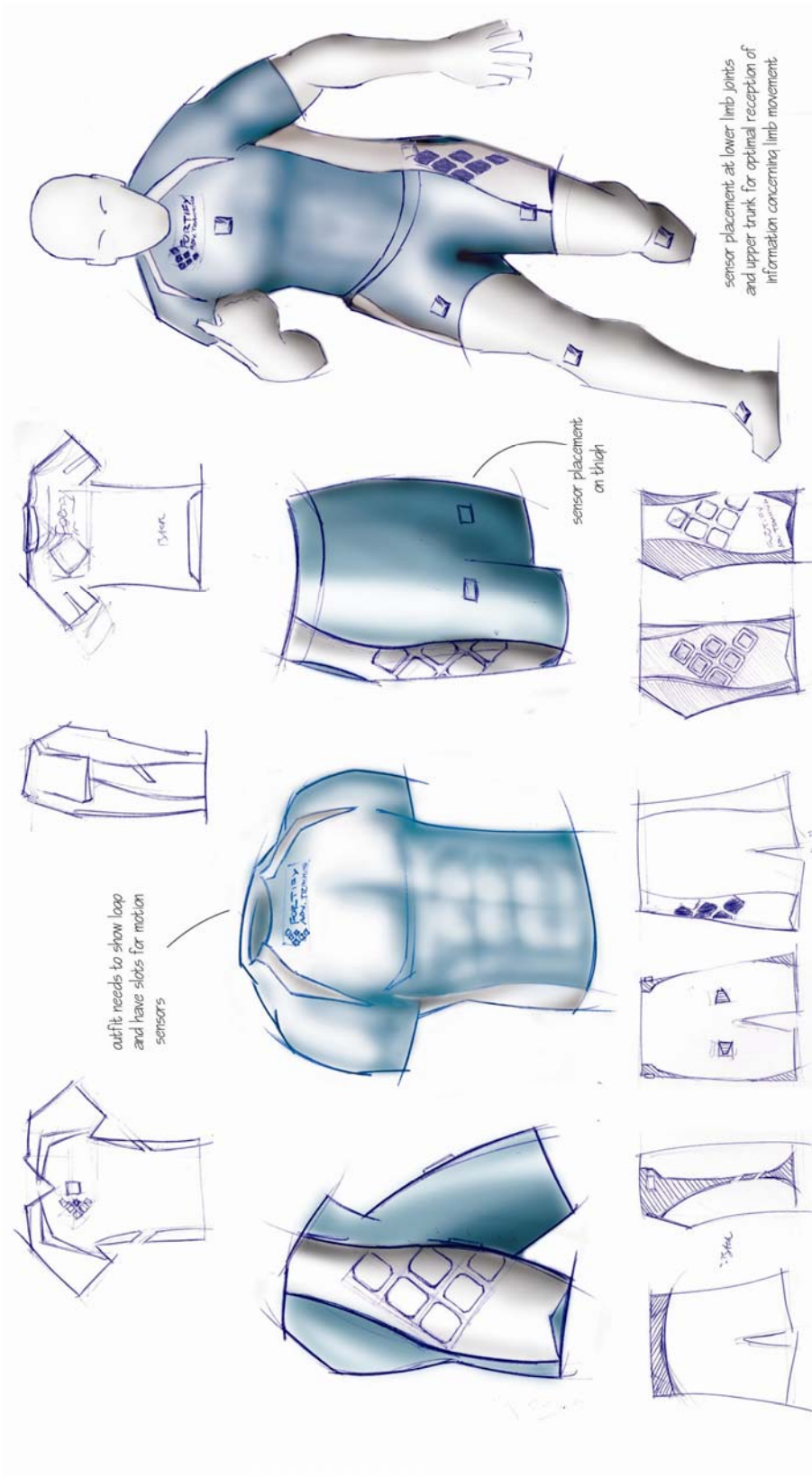
*The motion sensor houses motion detection and Bluetooth technology. It relays the body's velocity, rotation, and speed to the console. A rubber molding covers most of the plastic shell to give added durability while providing a shape that stays lodged within an elastic band.*



**Illustration 22: Refined Sketch 2**

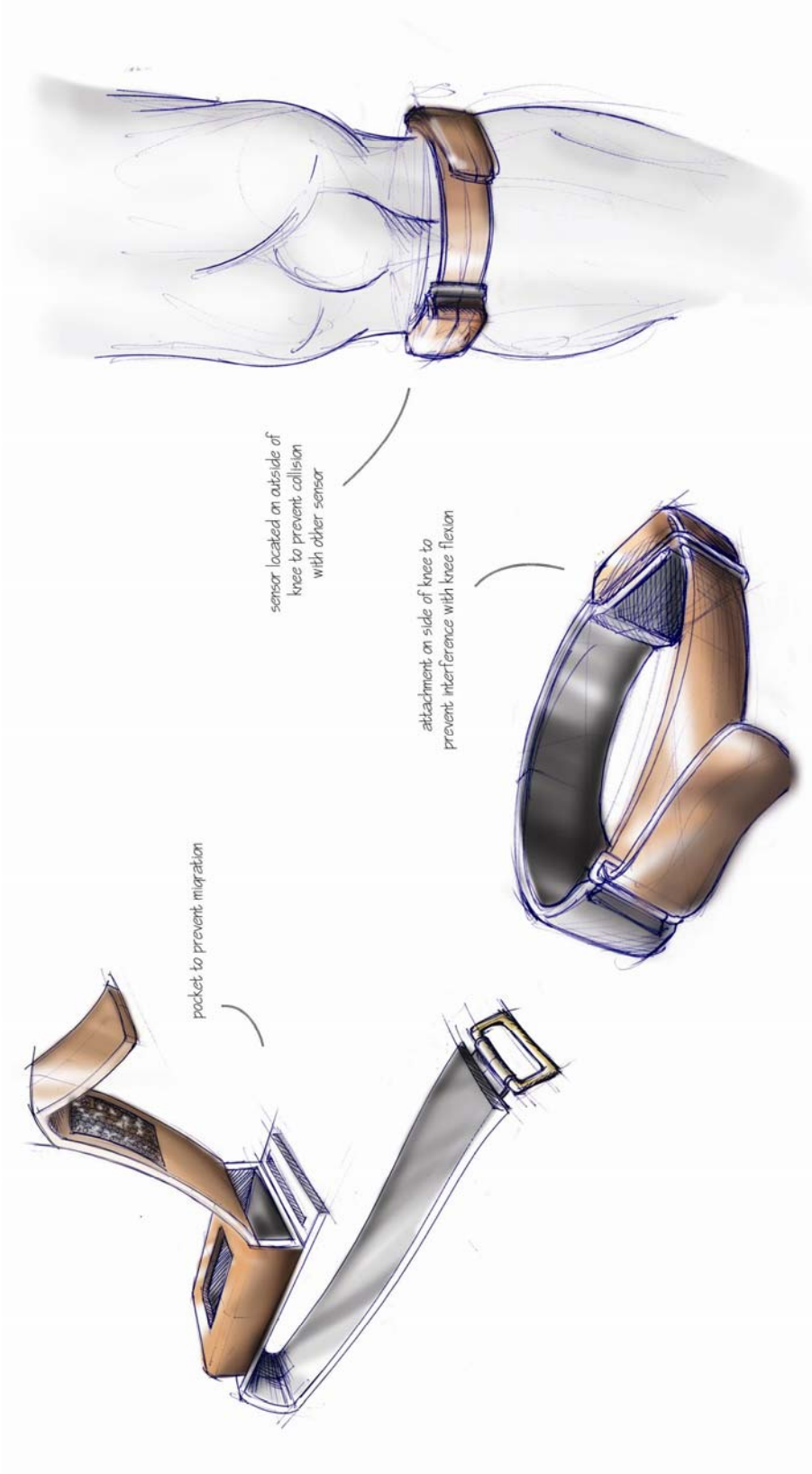
*The purpose of the shoe attachment is to create a housing that holds the sensor in place, avoiding migration, damage or dislodgement. The strap consists of a Velcro band that binds the top and bottom of the strap between the shoelaces. The button claps the straps together, lessening stress on the Velcro while in motion.*





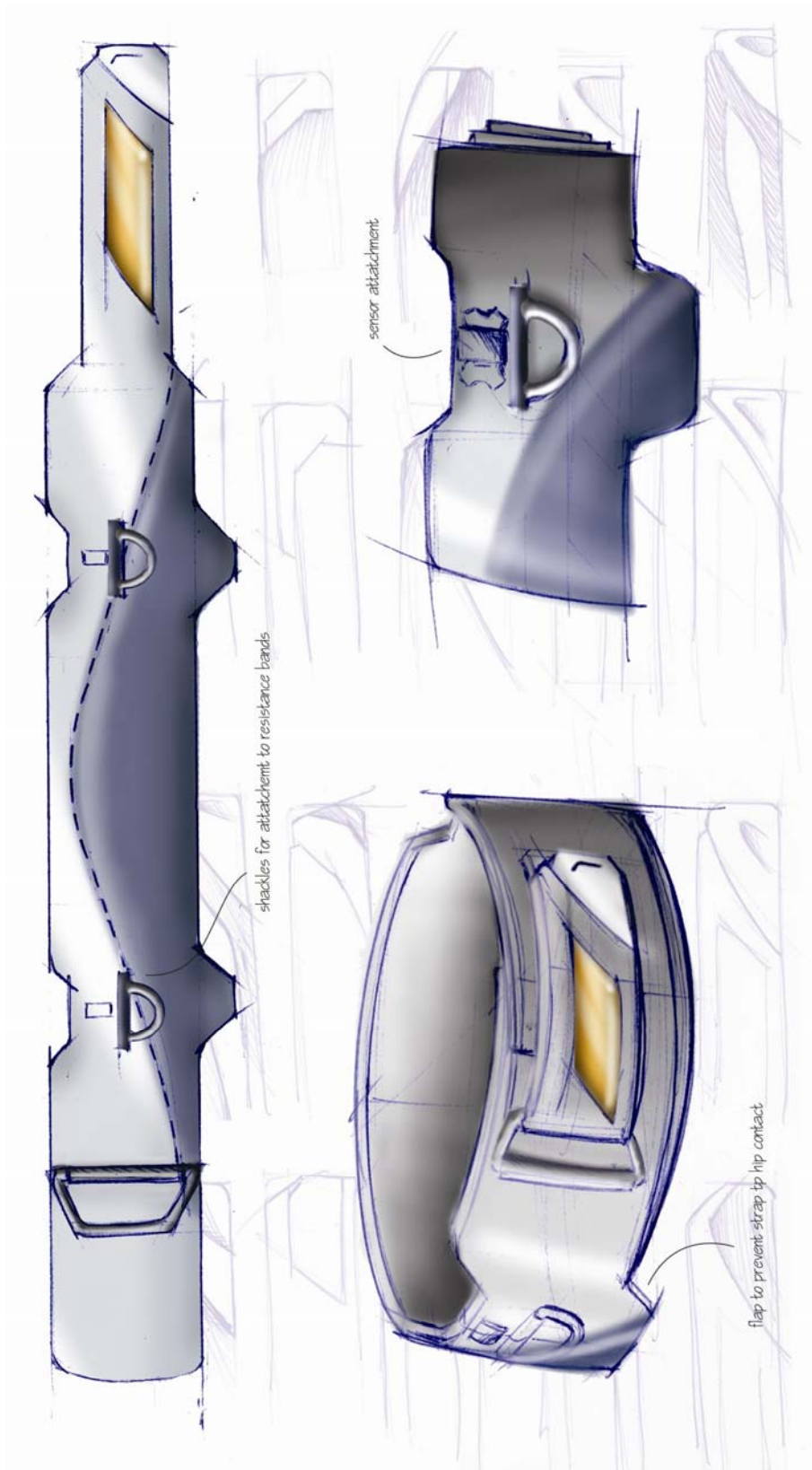
**Illustration 23: Refined Sketch 3**

*The outfit serves two purposes. It conveys the brand identity in an appealing way and houses the sensors, keeping them in close proximity with the user's body. The shirt and pants will be constructed out of microfiber, and the bands that compress the sensors against to the body will be made of an elastic synthetic fiber.*



**Illustration 24: Refined Sketch 4**

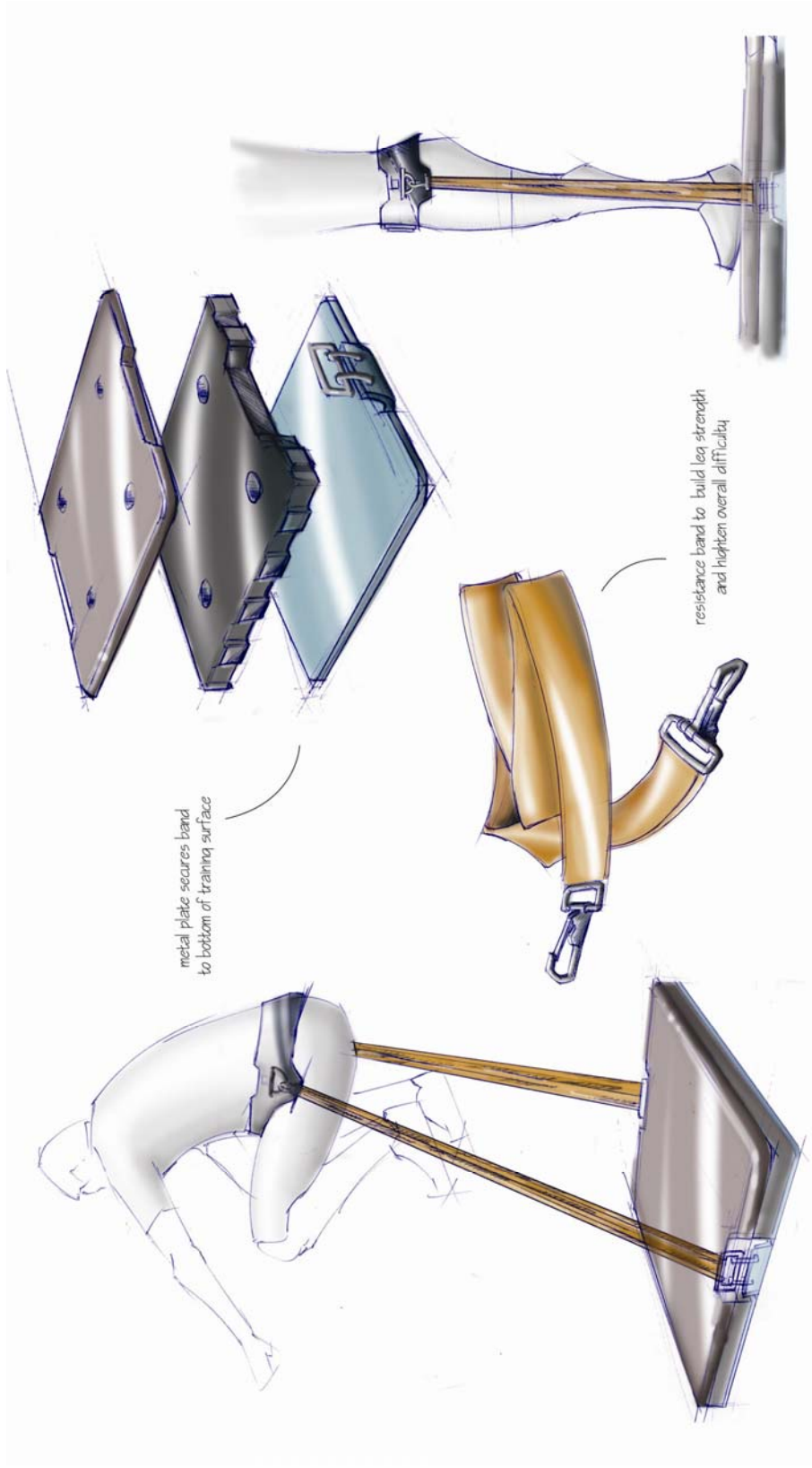
*The purpose of the knee attachment is to create a housing that holds the sensor in place, avoiding migration, damage or dislodgement. The strap consists of a Velcro band that loops back upon itself, fastening the band around the calf, directly below the knee.*



**Illustration 25: Refined Sketch 5**

*The belt attaches the resistance bands that extend from the training surface floor to the body of the user. There are two motion sensor slots located directly above the shackle-like rings. The two pad-like projections that descend from the outsides of the belt serve as a barrier between the hip and the resistance bands.*



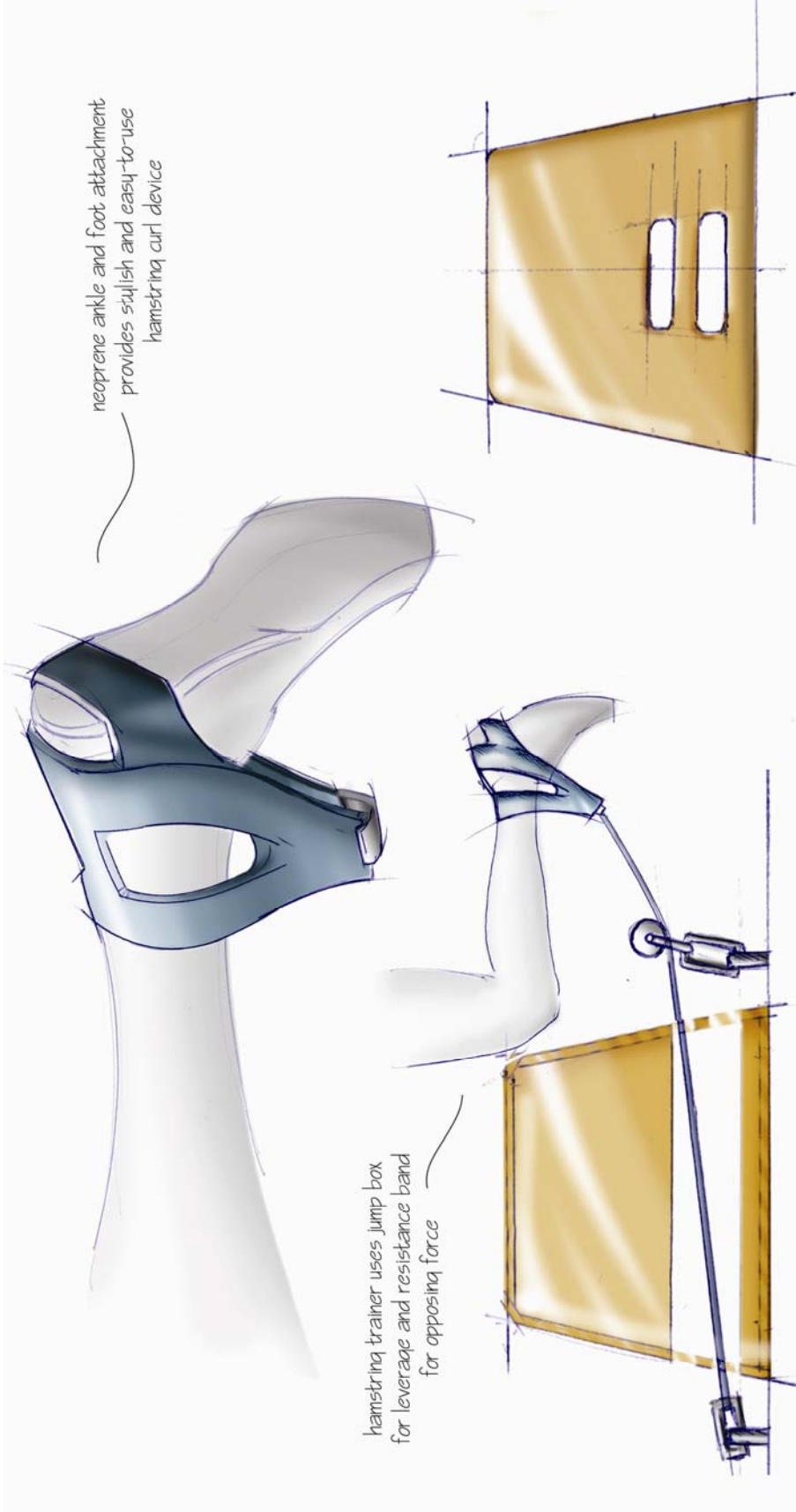


metal plate secures band to bottom of training surface

resistance band to build leg strength and heighten overall difficulty

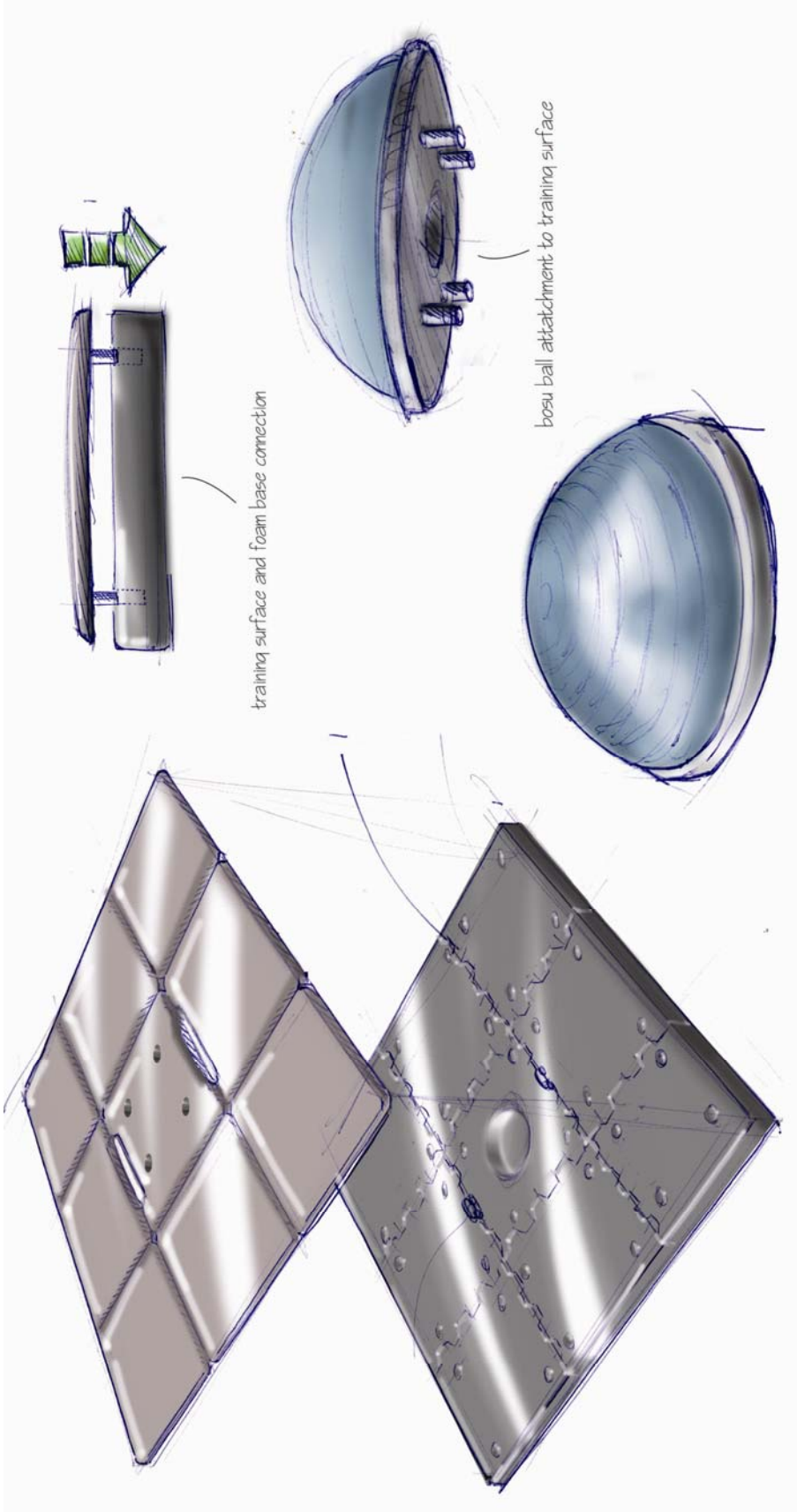
**Illustration 26: Refined Sketch 6**

*The resistance bands add difficulty to all applicable exercises and provide the overall device with greater strength-building properties. The resistance bands can work in junction with the Bosu ball, the jump box and agility ladder.*



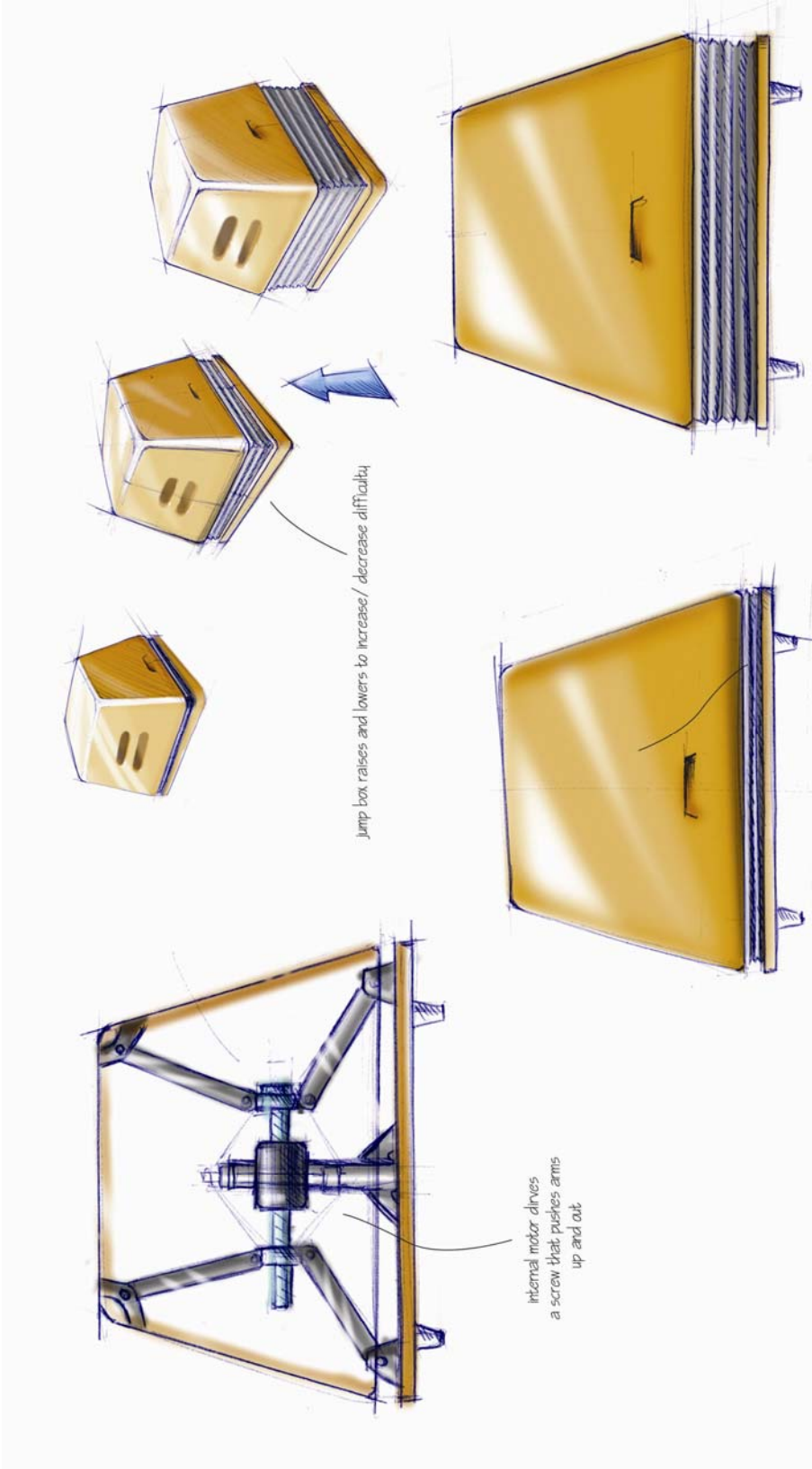
**Illustration 27: Refined Sketch 7**

*The resistance bands also can connect to an ankle and foot attachment for the purpose of training the user's hamstring. The band can pass through holes in the jump box and loop under a pulley to allow additional leverage for exercising a different part of the hamstring muscles.*



**Illustration 28: Refined Sketch 8**

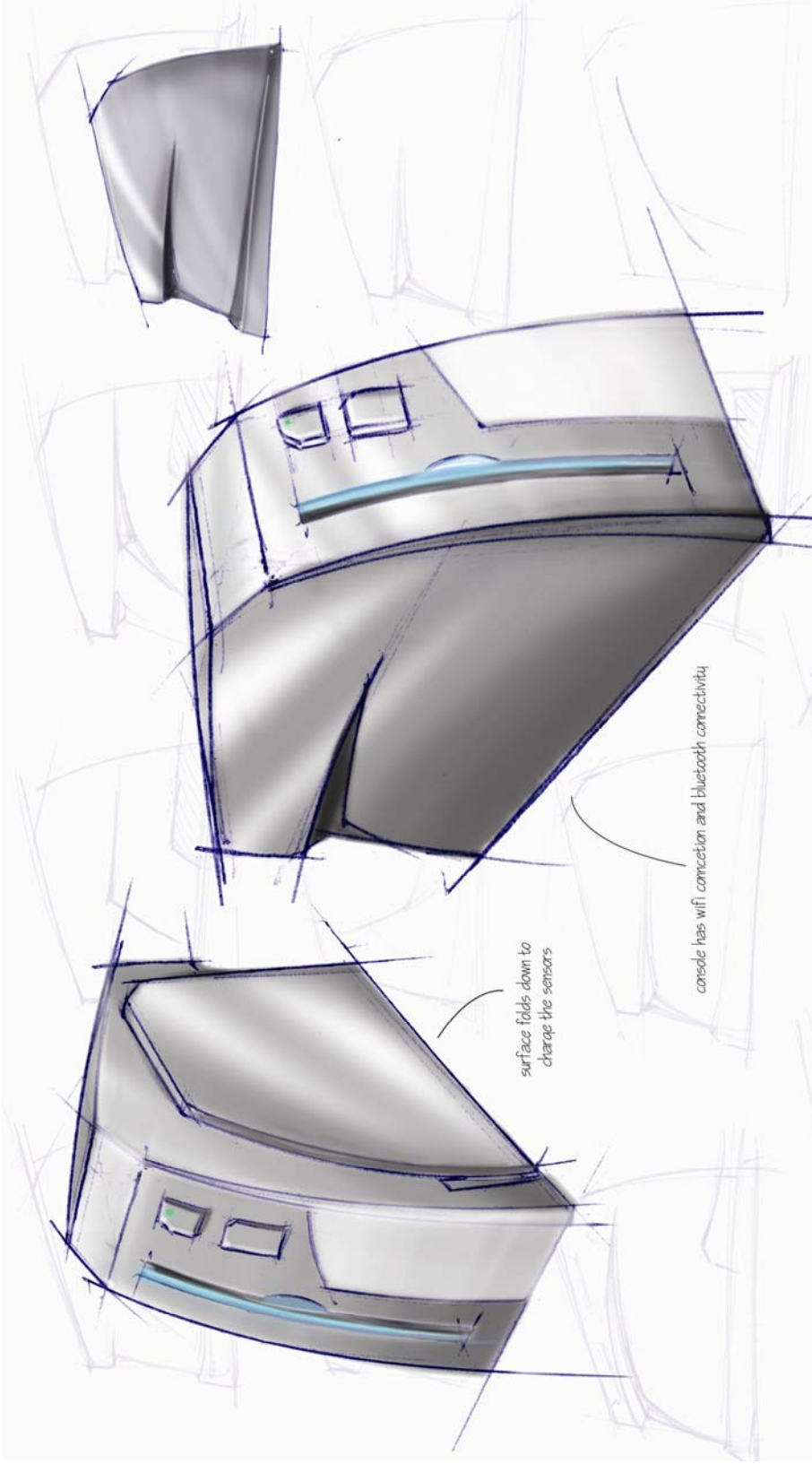
*The flooring was designed to have pegs descend from the upper training surface into the lower foam mats. This interaction keeps the surface from shifting during exercise and permits access to the items in storage below. The inserts on the bottom of the Bosu ball show how it and the jump box can be attached to the center panel.*



**Illustration 29: Refined Sketch 9**

*The jump box's main purpose is to train the legs and core through plyometric exercises. The box contains a motor that raises and lowers its height to increase or decrease difficulty. The gaps on the outer face allow the resistance band to pass through the box for hamstring exercises. The height can be raised to assist with such exercises.*





**Illustration 30: Refined Sketch 10**

*The console is the processor for all ingoing and outgoing information that occurs during physical training. The unit has an optical drive, a motherboard, onboard ram, graphics card, Bluetooth receiver, and information processor.*

*The console also has a fold-down wireless charging platform. It can support up to nine sensors at a time.*



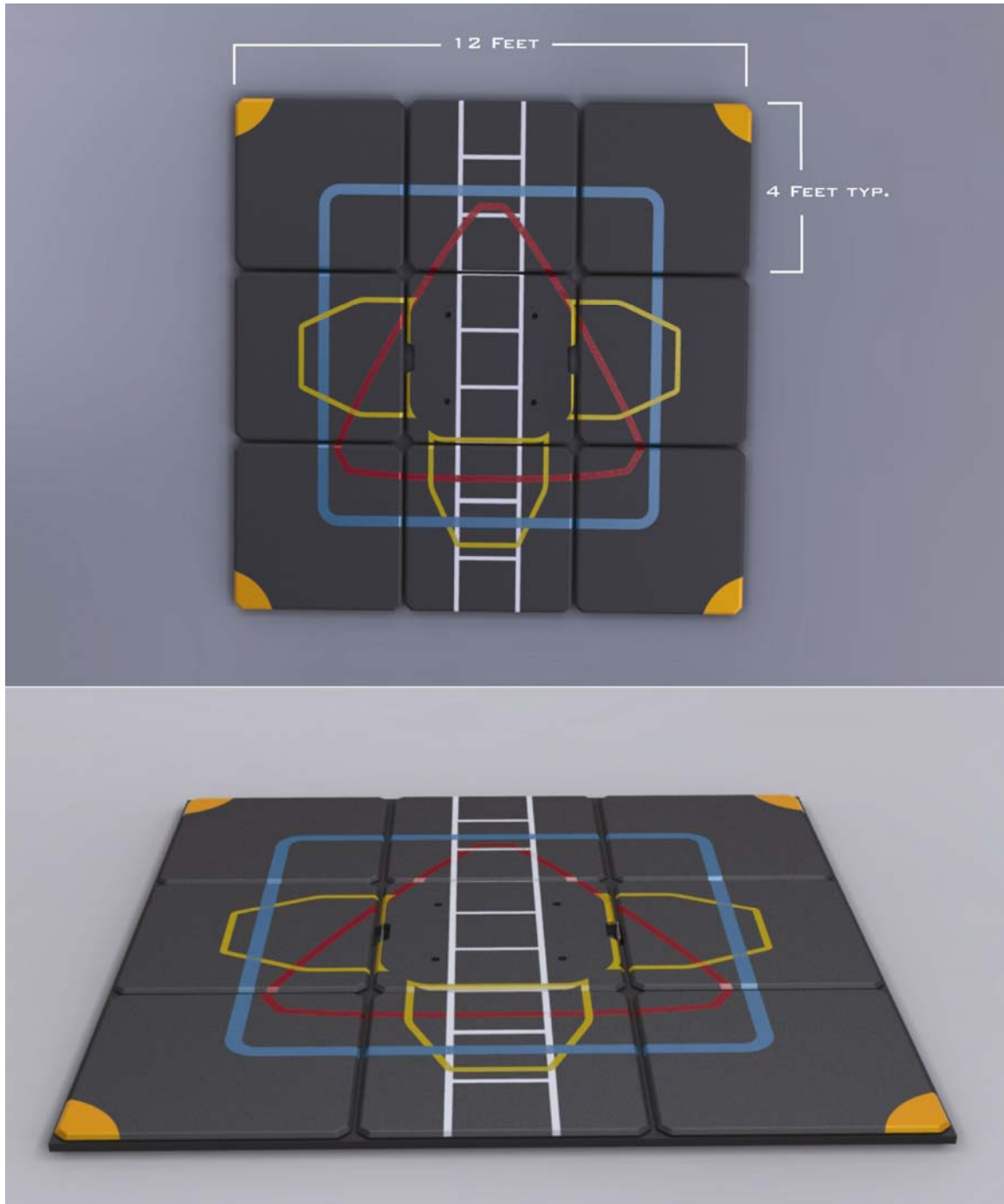
## CHAPTER 5: FINAL SOLUTION

### 5.1. Introduction

After the refined sketches were reviewed by the designers and biomechanists, the process of creating the training equipment began. Any issues that the reviewers presented were addressed and corrected on the final models. The concepts were reworked and refined in order to fit the necessary biomechanical functions and design requirements for the device until a satisfactory solution was reached.

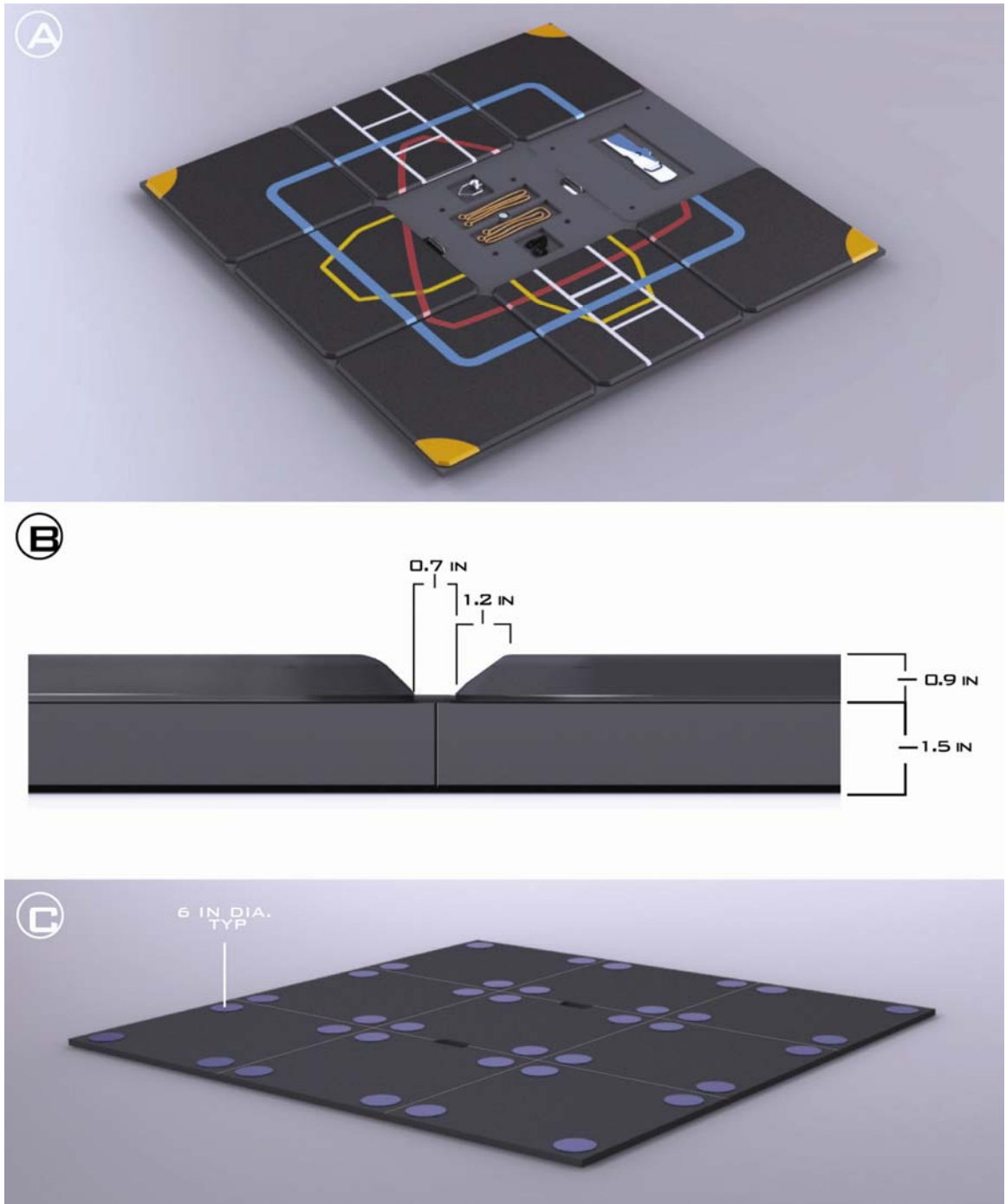
Some of their requirements were:

- Explain how to keep the training surface from shifting while in use.
- What type of footwear is to be worn while training?
- Create a cavity in the lower portion of the training surface that can house unused items.
- Redesign how jump box is raised and how it interacts with the hamstring trainer.
- Explain how all parts interact.
- Ensure that all products appear a part of the same “product family”.



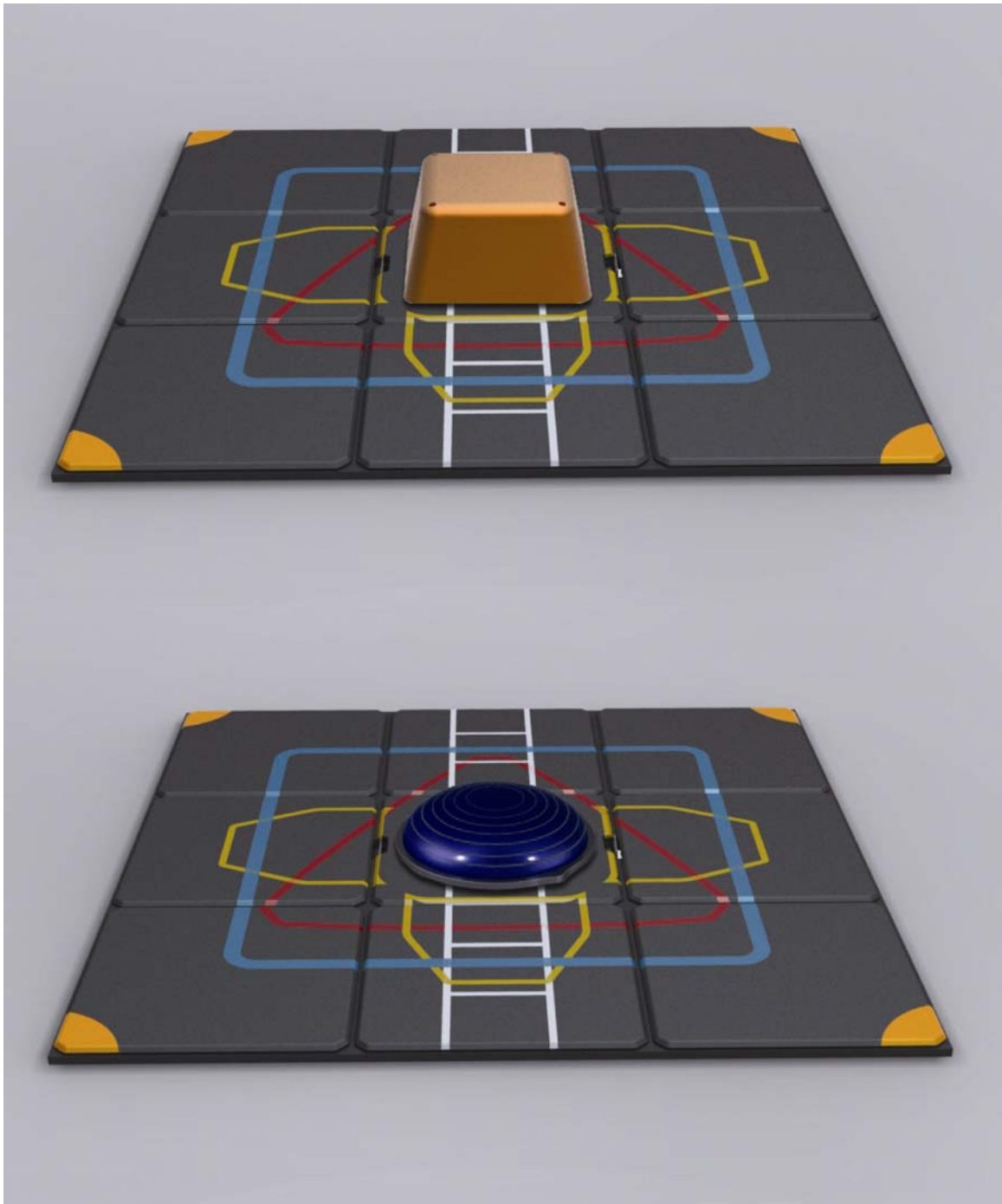
**Illustration 31: Final Training Surface**

*The training surface is constructed out of HDPE plastic. Each differently colored shape denotes the parameters for a collection of agility exercises. The blue and the orange corners are for four corner drills. The white is for ladder drills. The yellow is for plyometric drills. The red is for advanced agility drills.*



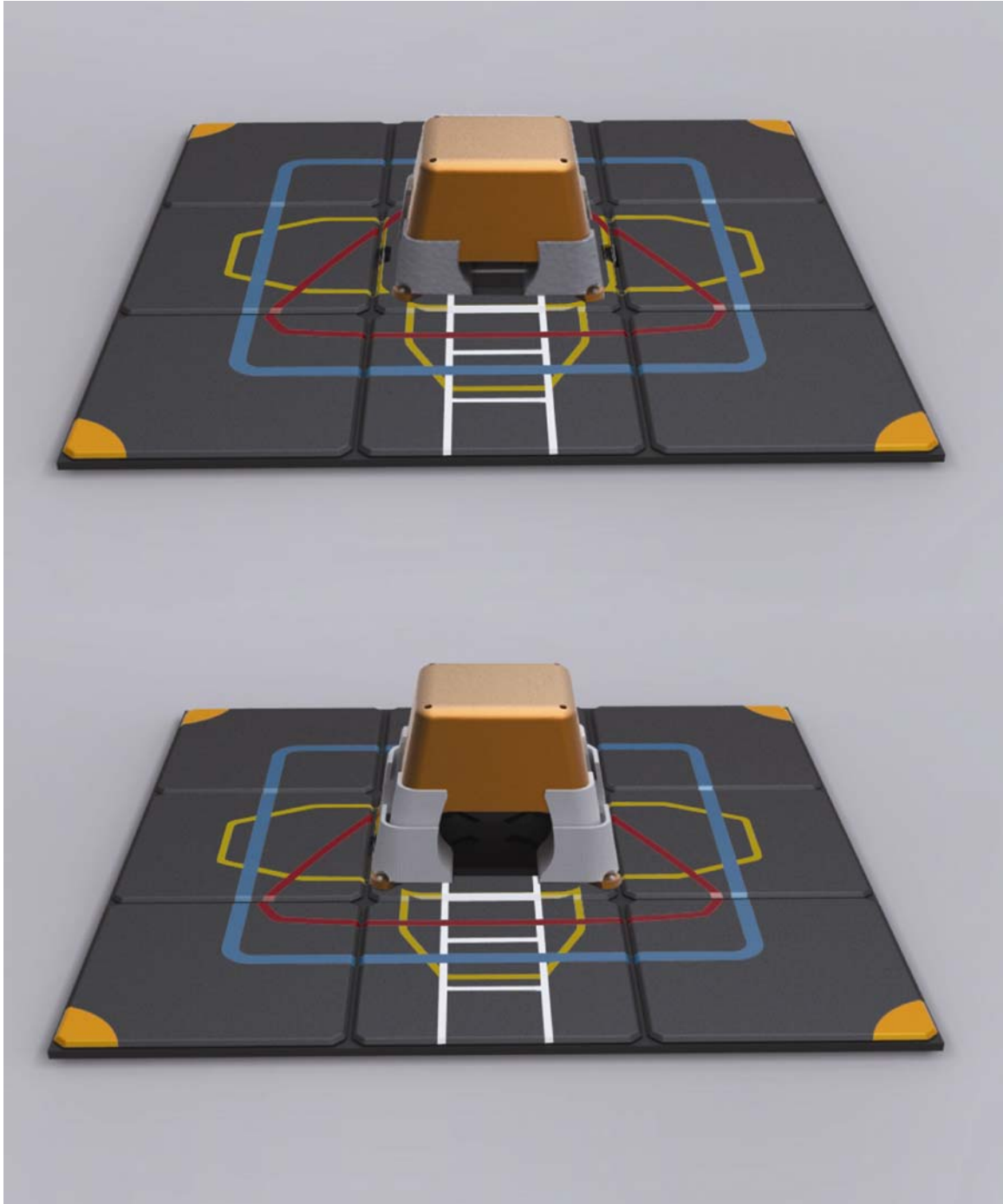
### Illustration 32: Training Surface Details

*Part (A) reveals the chambers where unused items can be housed. Part (B) displays the recesses between each unit of the training surface. Part (C) shows where the silicon pads, which prevent in-game shifting, are located on the bottom side of the training surface.*



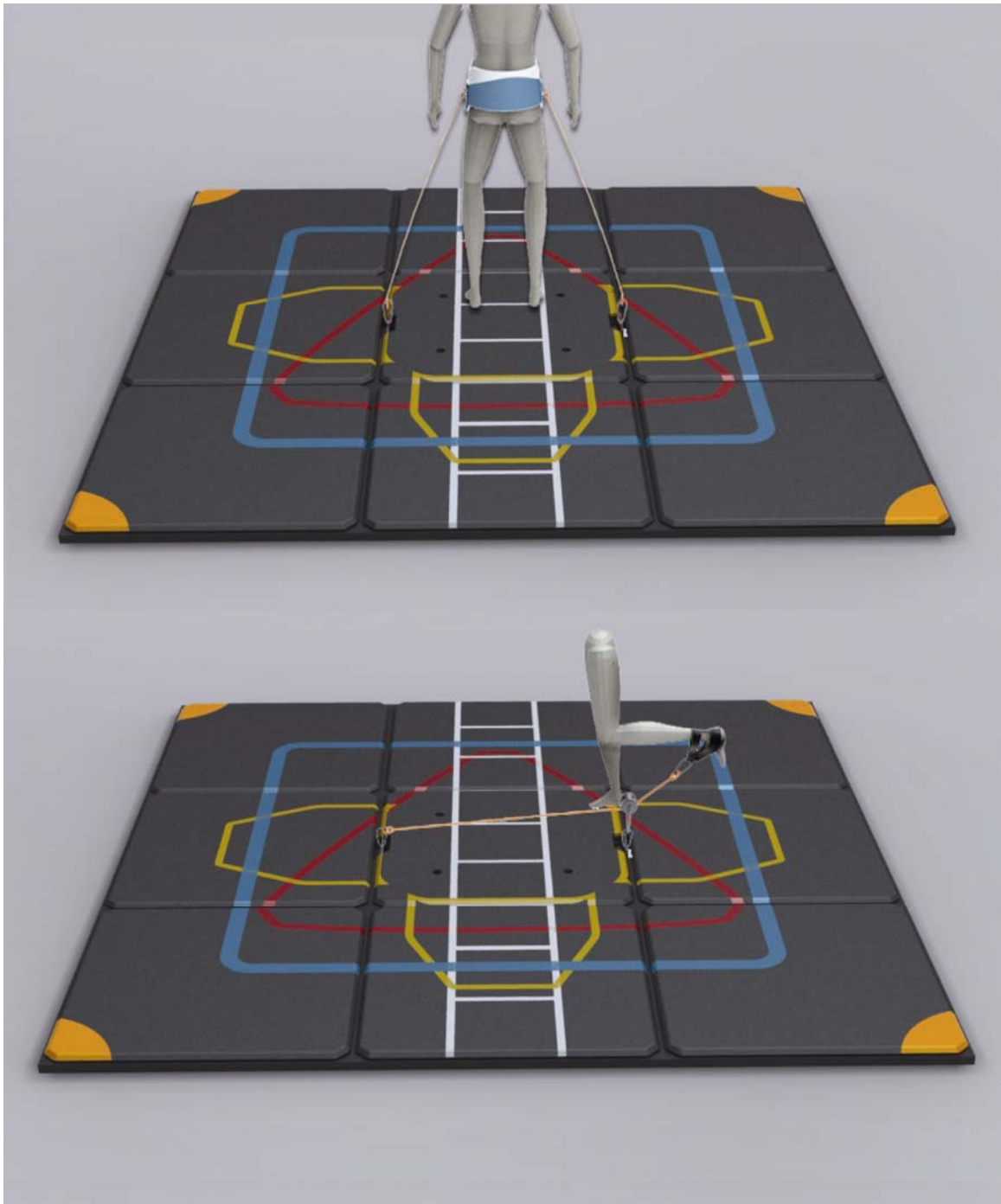
**Illustration 33: Training  
Device Application**

*The upper image shows how the jump box is oriented during training exercises. The user is to start and finish in one of the three yellow shapes for most exercises. The lower image displays how the Bosu ball is oriented during balance training.*



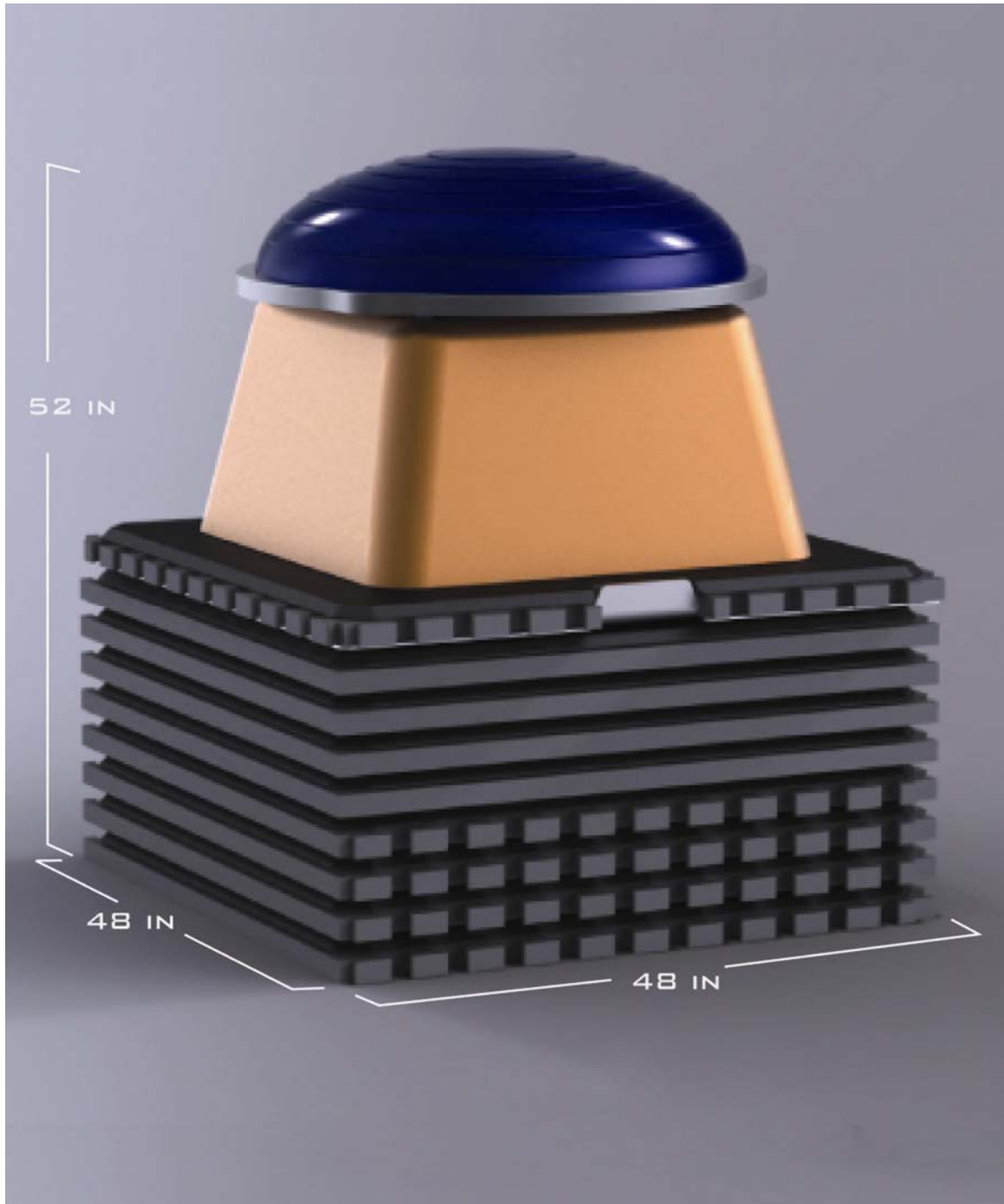
**Illustration 34: Jump Box Elevations**

*The jump box uses supports at its four corners to give the overall structure different elevations. The upper image shows the box at a height of 24 inches and the lower is shown at 30 inches. When not in use, these supports are housed underneath the box's plastic shell.*



**Illustration 35: Training Surface  
Interaction with Resistance Bands**

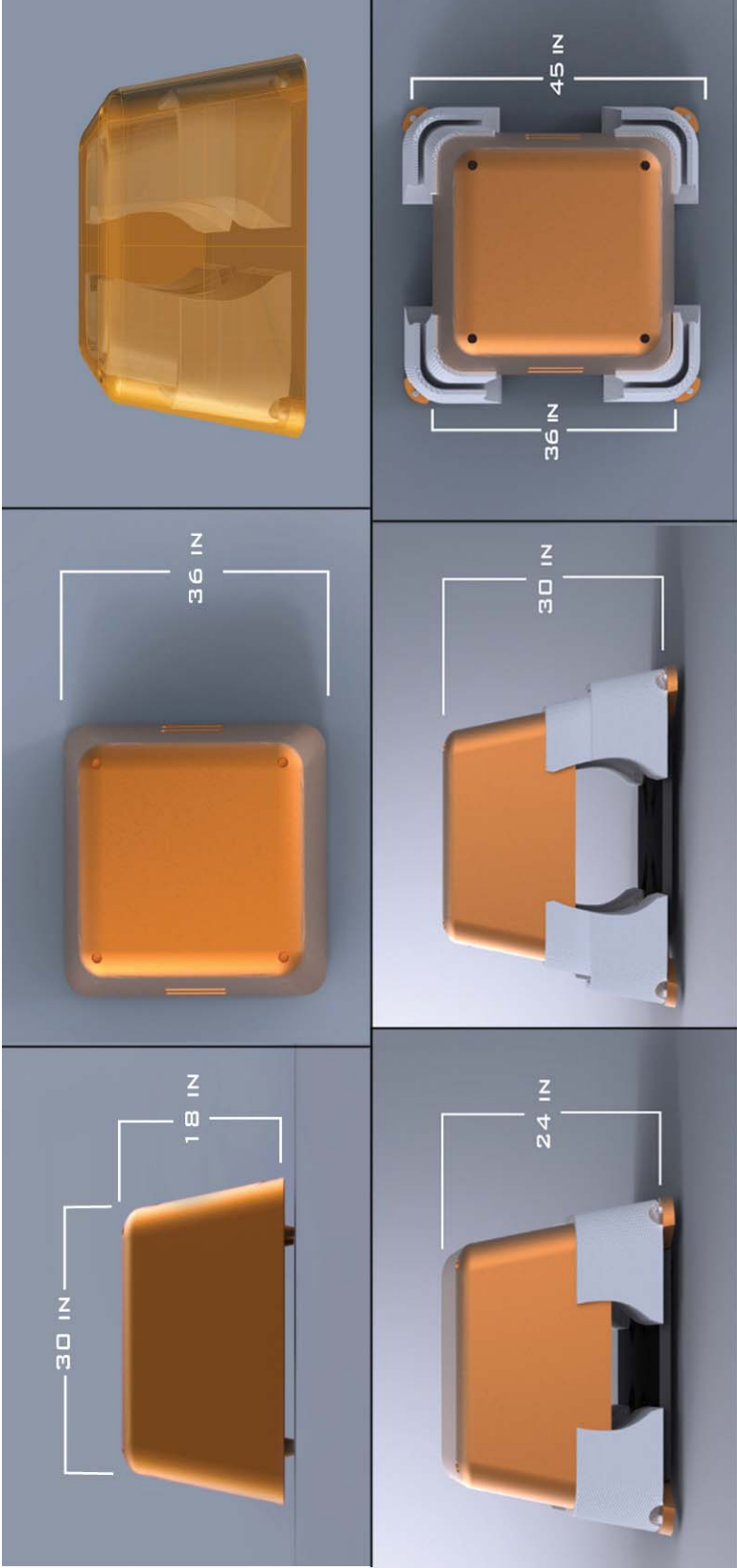
*The resistance bands connect to the training surface via a metal plate. The plate is located underneath the training surface and has handles that extend upwards through recesses in the center training surface. The bands are connected to the handles with karabiners.*



**Illustration 36: Packaging Dimensions**

*All the devices that are included in the training program are packed down into a 52" by 48" by 48" area. This includes the foam mat that is located under the training surface, the training surface, the resistance bands, belt, pulley, Bosu ball, jump box with internal supports, console and sensors.*

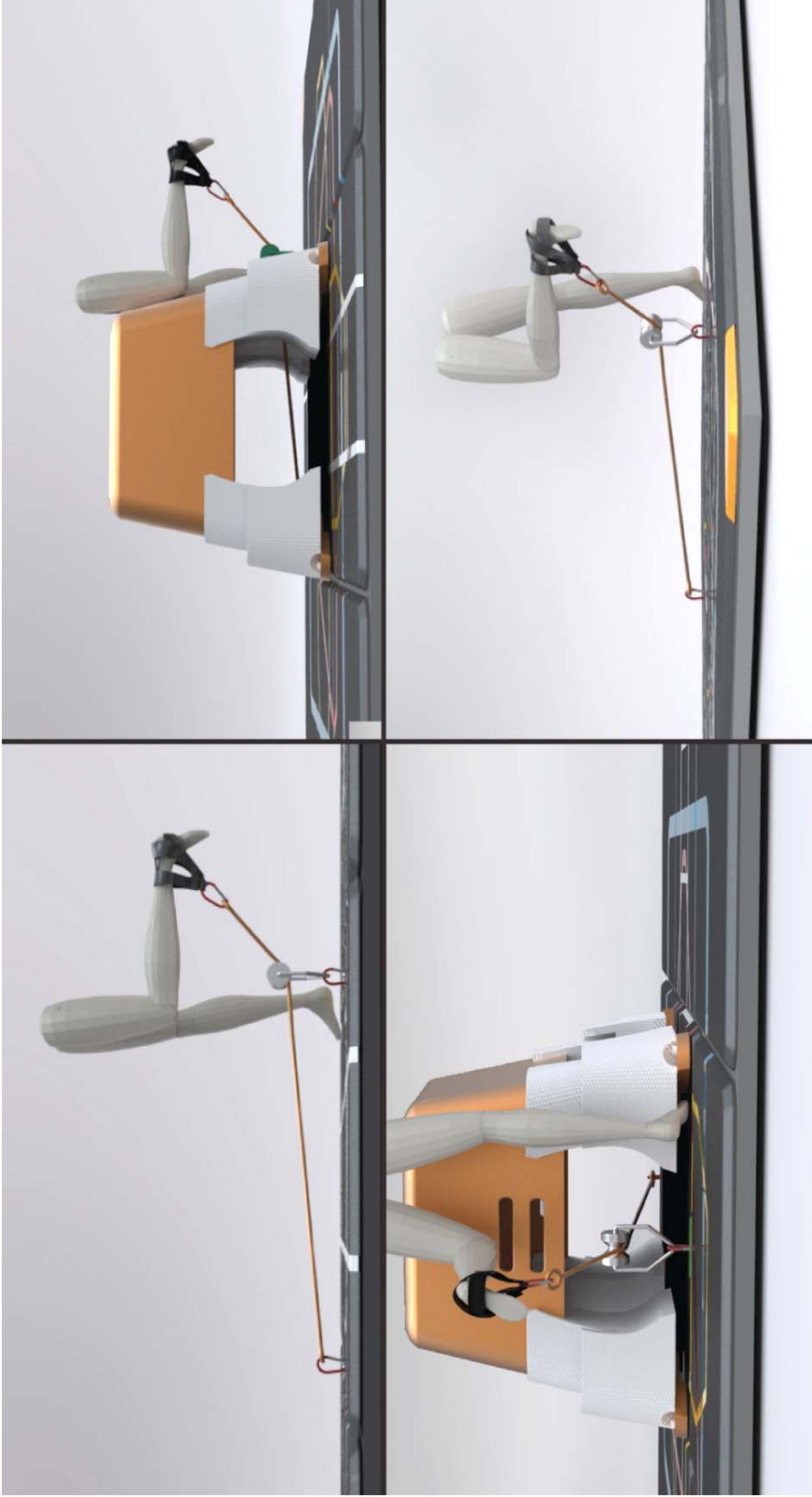




**Illustration 37: Jump Box Specifications**

*The jump box's purpose is to improve an athlete's explosiveness and lower body strength. The pegs on the lower portion of the top left image are inserted into holes in the training surface. The top right image displays how the elevating supports are housed within the shell of the jump box when they are not in use.*





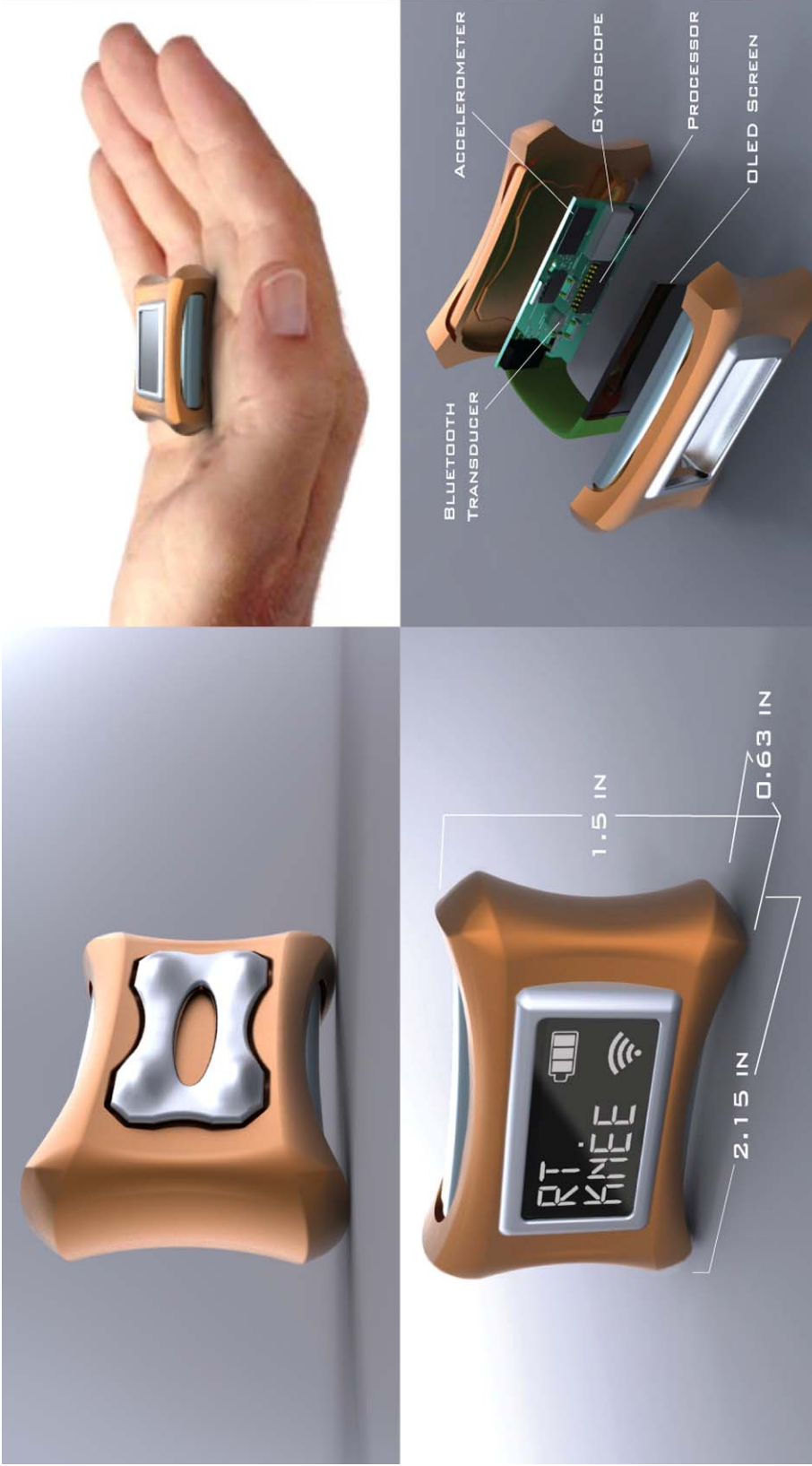
**Illustration 38: Hamstring Curls with Resistance Bands**

*There are two configurations that can be used when performing hamstring curls. Exercising without the assistance of the jump box will strengthen the calves as well as the lower portion of the hamstrings. When using the jump box for leverage, the user can more easily train the upper portion of their hamstrings.*



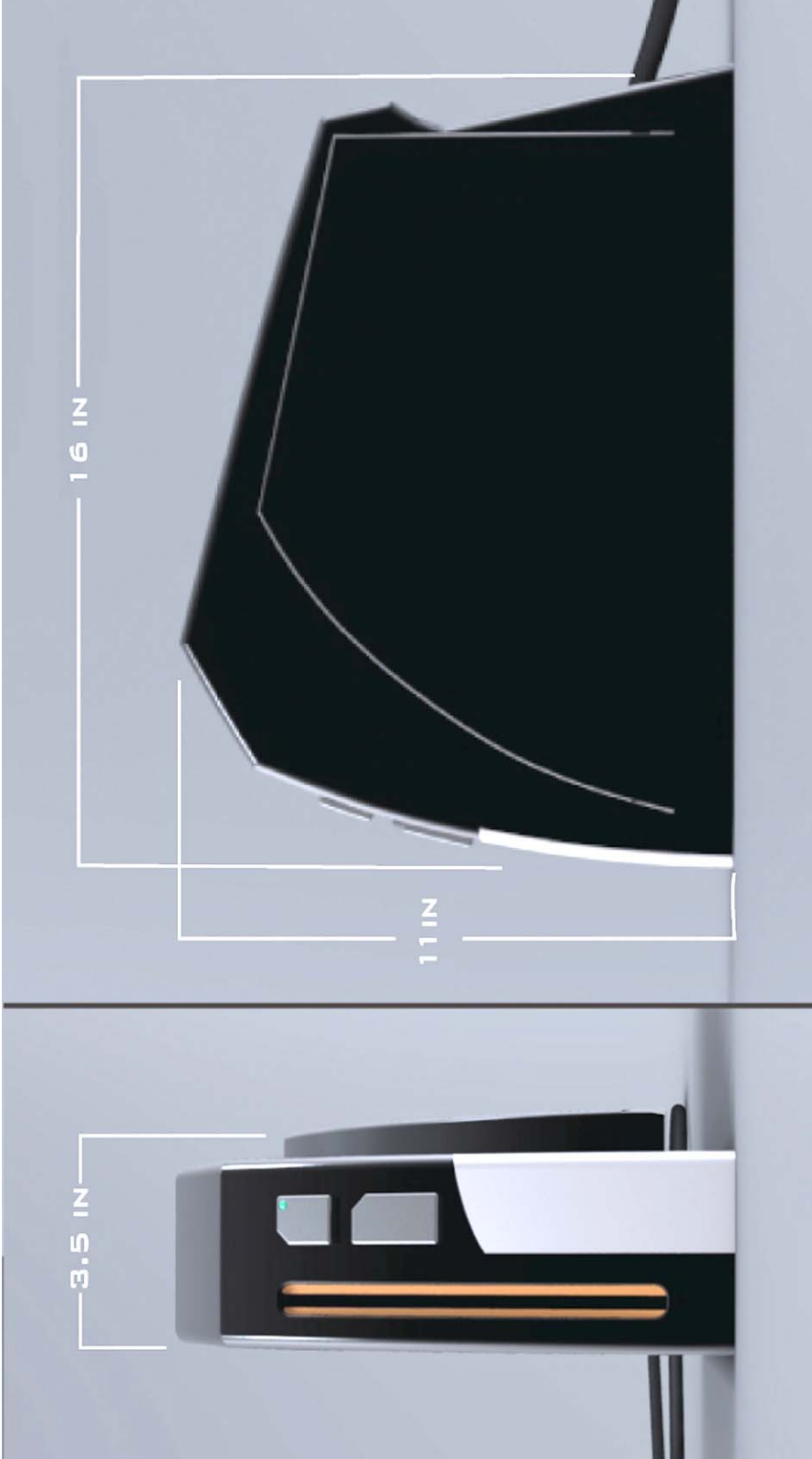
**Illustration 39: Belt and Resistance Bands**

*The belt is used for increasing the difficulty of plyometric exercises. It is attached to the resistance bands via two half shackles and a karabiner. The resistance bands attach to the training surface via a karabiner and two extended metal handles. The difficulty can be increased by adding thicker, shorter resistance bands.*



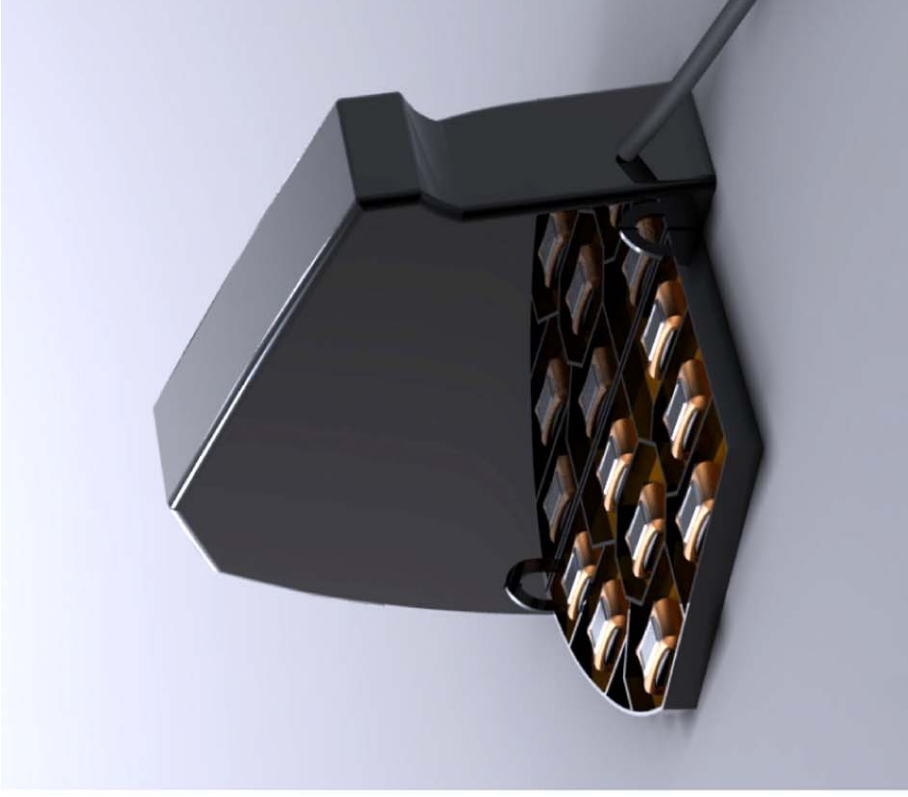
**Illustration 40: Real-Time Motion Sensor**

*The motion sensors constantly monitor the most important joint motions while the athlete performs an exercise. They inform the athlete if he or she is using the correct biomechanical technique in the exercises and alert him or her if he or she places his or her body in a dangerous anatomical position. They are attached to the athlete's clothing with a magnet, shown in the top left corner, with an attachable pocket or with an elastic band.*



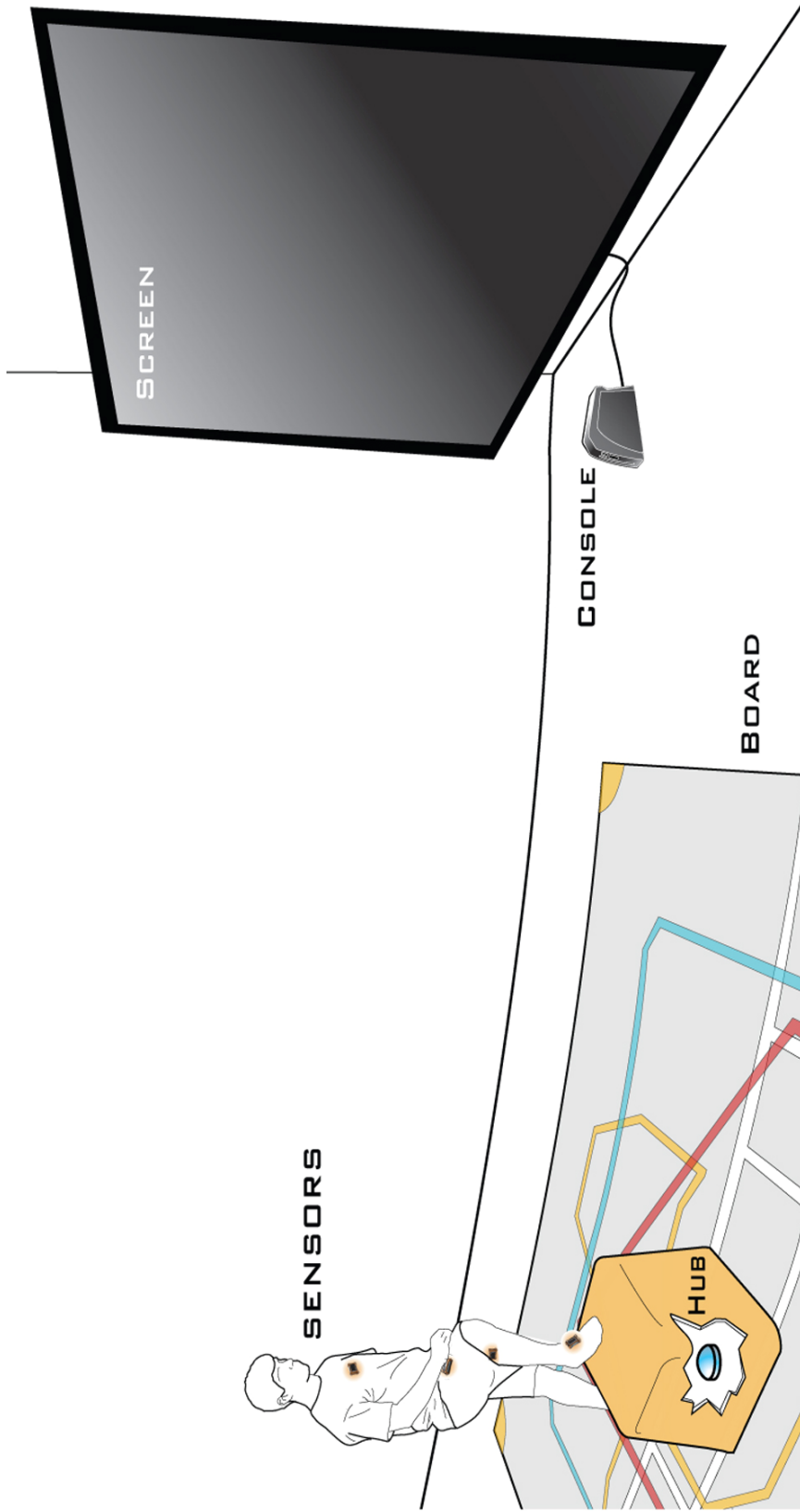
**Illustration 41: Console**

*The purpose of the console is to receive, compute and animate the information transmitted by the sensors. It also communicates with the "hub" sensor, located in the floor of the training surface, to calculate the position of the athlete relative to the training surface.*



#### **Illustration 42: Console Features**

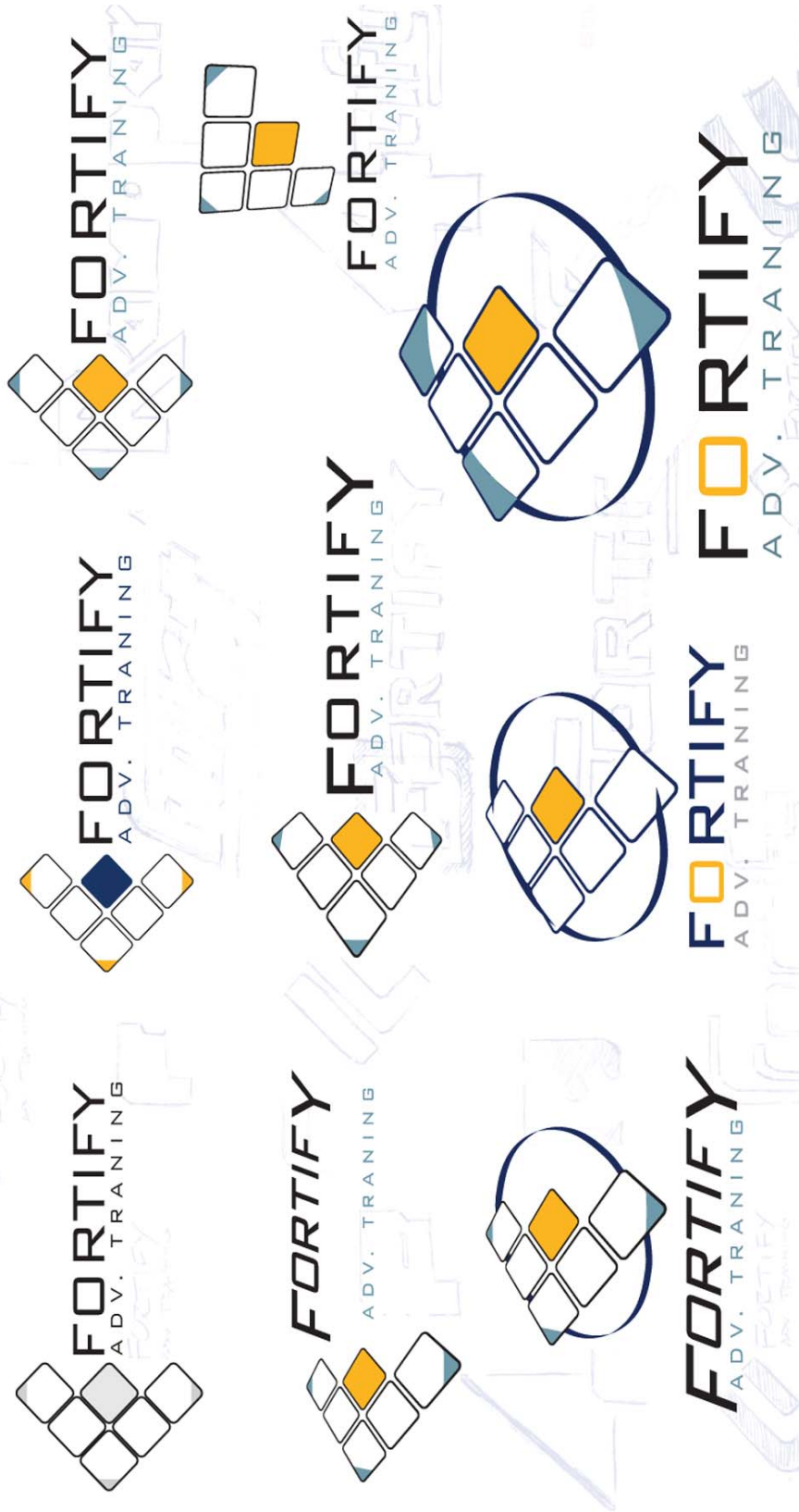
*The console not only receives and computes information; it charges the motion sensors and receives training information from a DVD or the internet. The charging mat folds down and charges the sensors wirelessly and connects with the internet using a wireless internet receiver.*



**Illustration 43: Device Interaction**

*The sensors will detect the user's velocity, rotation and acceleration through their internal components. They will sense each other's location using Bluetooth-based technology and send this information to the console. The console will send information to the "hub" sensor and receive back information to calculate the athlete's position relative to the training surface. All received information will be processed and sent to the screen for game play.*





**Illustration 44: Brand Identification**

*All of the devices created for this project and exercise system need to be classified under one name and one product family. The name "fortify" was chosen to reflect that, by using the training program and training equipment, one can reinforce the structures of one's body and lessen the chance of becoming injured. The bottom right logo was chosen for its successful abstraction of the training surface and overall impact.*



**Illustration 45: Sensor and Suit Application**

*Sensors were specifically placed at the optimal locations of the athlete's outfit to receive the most accurate information for lower body training. There are sensors on the feet, below the knees, the mid thigh, the outer hip for leg movements and the chest for postural positioning. The suit also allows area for graphical application of the logo.*



## 5.2 Other Considerations

The shoe wear that is prescribed for use during training is that tailored to running and cross training. Wearing these shoes allows the correct amount of shoe-to-surface interaction. The outfit that is to be worn while training is very similar to the one shown in Illustration 34. It needs to be made of a dry fit or microfiber material and fit closely to the body to prevent the measuring of any unwanted movements. The sensors are attached to the outfit or the body by a magnet, located on the back of the sensor, an attachable strap and pocket (Illustration 13 and 14) or by an elastic band (Illustration 12 and 15).

Video and audio instruction and feedback are important elements to the success of the training program. An athlete needs to know how to correctly perform an exercise and be critiqued on the quality of the movements performed. Ideally, a single training exercise would start out with the user standing on the board. A computerized instructor would demonstrate and explain the benefits, correct movements and helpful hints on how to complete the upcoming exercise. Once the trainer has concluded his or her instruction, the screen would be replaced by a computerized representation of the athlete. This representation would mirror all of the movements that the actual user would make. The program would time and track the user's movements and report back to the user how he or she performed. If, during the activity, the athlete assumed a physical position that would increase his or her risk of suffering an injury, the

exercise would stop, and the computerized trainer would inform the individual of that error.

### **5.3 Summary of Chapter**

Chapter 5 summarizes the function and visual interpretation of the required training devices that are to be used in the training program. The final solution strived to produce devices that were attractive to athletes and athletic trainers. It also strived to allow the greatest amount of exercises to be performed on the fewest number of training devices. It was also important to create space where unused items could be stored for quick retrieval. The end result theoretically meets its functional goals and the goals of this study.

## CHAPTER 6: CONCLUSION

### 6.1 Summary of Project

This thesis project began with the identification of a problem, which was the abundance of ACL injuries to young adult athletes and the lack of preventative devices or training programs. The goal of this thesis was research the potential causes of an ACL injury, create a guideline for lowering the instances of the ACL injury and similar noncontact injuries and create a model that would theoretically lower the chance of an athlete sustaining an ACL injury. The initial research established the negative effects of sustaining an ACL injury as well as identifying the bones, ligaments, tendons, cartilage, and muscles that contribute to the stability of the knee joint.

The physical traits that researchers claimed to contribute to ACL injuries were categorized into three different areas of internal factors. These factors were anatomical factors, neuromuscular factors, and biomechanical factors. It was identified that rarely was there just one or two factors that contribute to an ACL injury, but a combination of many contributing factors. The next task was to locate and examine the training programs that had attempted to train against ACL injuries and identify the equipment they used and their rate of success.

A method was created with the intention of combining all the previously identified information and synthesizing it into an exercise program and ultimately a training device.

This method included identifying what essential skills were necessary for an individual to be successful at a specific position in a specific sport. It questioned the athlete whether he or she had sustained an injury to a body part whose involvement was necessary for success at the particular position. If an internal risk factor could be improved through additional training, it would become a focus of the training program. If the factor could not be improved, the training program would avoid exercising and placing additional stress on the “at risk” area.

All of these inputs were collected and synthesized; from them, a training program was created. The training program’s goal was to push an athlete to achieve and surpass the essential skills that are necessary at a chosen position. Finally, training equipment was chosen that could fulfill the needs of the training needs of the athlete and effectively perform the greatest amount of exercises while occupying the least amount of space. The chosen devices were then designed to not only perform their exercise based task, but also to appear as a part of a product family.

The creation of these devices was explored through sketches. These sketches denoted the necessary actions to be performed, structural elements and the potential for digital interaction. These concepts were reviewed by

designers and biomechanists. The designers reviewed the sketches for basic function and potential for mass production, while the biomechanists reviewed the sketches for the ability to train muscle groups, avoid user injury and monitor the participant's athletic technique. The concepts were refined to fit the reviewers' specifications and to implement applicable training techniques from the successful training programs. The training system monitors an individual during athletic activity, offers correction to incorrect form and alerts the user when he or she is in dangerous anatomical positions. The final result is a training device that provides a training program and training equipment that, if used correctly and consistently, would lower one's chances of sustaining an ACL injury.

## **6.2 Recommendations for Future Study**

Though the training program and training equipment was based on successful training programs and training devices, further testing would need to be done to validate the medical and physical benefits of the training device.

It would also be beneficial to elaborate on the digital interaction between athlete, training device and game play. Having a computerized trainer is a great way to instruct and correct the user. However, different people respond to different types of encouragement. Some respond better to hopeful words of edification while others respond better to harsh critiques and negative feedback. Additional considerations would need to be taken to customize the computerized trainer to specific age groups and sexes for appropriate user-centered feedback.

This type of input would make an appropriate addition to the design methodology that ultimately creates the training program.

The aspect of digital interaction that could be elaborated is the rewards that a user receives after he or she completes a specific number of challenges. Some rewards could be access to additional abstract, lighthearted training exercises, while other rewards could offer customization of the on-screen athlete. The ability to choose a different trainer could also be a reward, specifically if the user could change the trainer to one of their athletic role models.

Another future consideration that would be valid is to make the device adaptive for outdoor training or practicing facility. It would be beneficial for an athlete to train on their potential performing surface while still getting the benefits of receiving crucial information about their performance in real time. On the same note, adapting the training system to outdoor use would also allow for the monitoring of multiple athletes simultaneously. Doing so would permit coaches and trainer to see how the athletes react to the presence of other individuals during team based performances.

## REFERENCES

- ACL Reconstruction Cost.* (2009, January). Retrieved September 8, 2009, from Cost of ACL Reconstruction - Get Information and Cost Guidelines - Cost: <http://www.costhelper.com/cost/health/acl-reconstruction.html>
- Aiello, M. R. (2009, January 26). *Knee, Meniscal Tears (MRI): eMedicine Radiology.* Retrieved July 14, 2009, from [emedicine.medscape.com](http://emedicine.medscape.com/article/399552-overview): <http://emedicine.medscape.com/article/399552-overview>
- Bahr, B., Holme, I. (2003). Risk factors for sports injuries—a methodological. *British Journal of Sports Medicine* , 384-392.
- Beynon, Bruce D., Slauterbeck, James R. (2007). Intrinsic and Extrinsic Forces Associated With ACL Injury. In T. Hewett, *Understanding and Preventing Noncontact ACL Injuries* (pp. 259-263). Champaign: Human Kinetics.
- Buchanan, P. A. (2004). *Developmental perspectives on basketball players' strength, knee position in landing, and ACL injury gender differences.* Oregon: Kinesiology Publications, University Oregon.
- Busam ML, P. M. (2008). Complications of anterior cruciate ligament reconstruction with bone-patellar tendon-bone constructs: care and prevention. *American Journal of Sports Injury* , 379-94.
- Cluett, J. (2008, January 1). *ACL Injuries.* Retrieved May 11, 2009, from About.com: <http://orthopedics.about.com/cs/aclrepair/a/acl.htm>
- Cook, G., Burton, L., and Fields, K. (1999). Reactive Neuromuscular Training for the. *Journal of Athletic Training* , 194-201.
- Floyd, R. T. (2007). *Manual of Structural Kinesiology.* New York: McGraw Hill.
- Flynn, R. et al., Pedersen, C., Birmingham, T., Kirkley, A., Jackowski, D. and Fowler, P. (2005). The Familial Predisposition Toward Tearing the Anterior Cruciate Ligament. *33* (1), pp. 23-28.

- Garrett Jr., W. E. and Yu, B. (2007). Congruence Between Existing Prevention Programs and Research on Risk Factors and Mechanisms of Noncontact ACL Injury. In S. J. Timothy E. Hewett (Ed.), *Understanding and Preventing Noncontact ACL Injuries* (p. 115).
- Gray, H. (1974). *Gray's Anatomy*. Philadelphia: Running Press Book.
- Griffin, L., Albohm, M., Arendt, E., Bahr, R., Beynnon, B., DeMaio, M., Dick, R., Engebretsen, L., Garrett, W., Hannafin, J., Hewett, T., Huston, L., Ireland, M., Johnson, R., Scot. (2006). Understanding and Preventing Noncontact Anterior Cruciate Ligament Injuries. *The American Journal of Sports Medicine*, 1512-1531.
- Hewett, T. E. (2007). An Introduction to Understanding and Preventing ACL Injury. In *Understanding and Preventing Noncontact ACL Injuries* (pp. xxi-xxviii).
- Ho, S. (2009, July 1). *What Can I Do To Prevent Reinjuring My Anterior Cruciate Ligament?* Retrieved September 8, 2009, from <http://abcnews.go.com/Health/MensHealthQuestions/story?id=7927782>
- Ingram, J., Fields, S., Yard, E., and Comstock, R. (2008). Epidemiology of Knee Injuries Among Boys and Girls in US High School Athletics. *The American Journal of Sports Medicine*, 1116-1122.
- Kvist, J., Ek, A., Sporrstedt, K., Good, L. (2005). Fear of re-injury: a hindrance for returning. *Knee Surgery, Sports Traumatology, Arthroscopy*, 13, 393–397.
- Lathrop, S. (2008). *Stedman's medical dictionary for the health professions and nursing*. (Illustrated 6th ed. ed.). Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins.
- Marks, P., Droll, K., Cameron-Donaldson, M. (2007). Does ACL Reconstruction Prevent Articular Degeneration? In *Understanding and Preventing Noncontact ACL Injuries* (pp. 31-45).
- Marshall, S.W., Padua, D., and McGrath, M. (2007). Incidence of ACL Injury. In T. M. Hewett, S. J. Shultz, & L. Y. Griffin (Eds.), *Understanding and Preventing Noncontact ACL Injuries* (p. 10). Champaign, IL: Human Kinetics.



- Miller, G. K. (1996). *The Meniscus (Cartilage)*. Chicago: WINDY CITY ORTHOPEDICS & SPORTS MEDICINE.
- Mueller, F. O. (2001, July). *Catastrophic Head Injuries in High School and Collegiate Sports*. Retrieved November 4, 2009, from NATA Journal of Athletic Training: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC155424/>.
- Powell, J., Barber-Foss, K. (1999). Injury Patterns in Selected High School Sports: A Review of the 1995-1997 Seasons. *Journal of Athletic Training*, 277-284.
- Riley, R. (2009, July 2). *Townsend Motion Hinges Patents*. Retrieved August 2, 2009, from Townsend Design: [http://www.townsenddesign.com/Townsend\\_Design/Townsend\\_Design\\_A\\_Leading\\_Brace\\_Manufacturer\\_files/Catalog.pdf](http://www.townsenddesign.com/Townsend_Design/Townsend_Design_A_Leading_Brace_Manufacturer_files/Catalog.pdf)
- Shultz, S. J.; Nguyen, A.D.; Beynnon, B. D. (2007). Anatomical Factors in ACL Injury Risk. In *Understanding and Preventing Noncontact ACL Injuries* (pp. 239-258).
- Stapleton, T. R. (2008). *The Posterior Cruciate Ligament*. Retrieved July 21, 2009, from Hughston Clinic, P.C.: <http://www.hughston.com/hha/a.pcl.htm>.
- Marshall, S.W., Padua, D., McGrath, M. (2007). Incidence of ACL Injury. In T. M. Hewett, S. J. Shultz, & L. Y. Griffin (Eds.), *Understanding and Preventing Noncontact ACL Injuries* (p. 10). Champaign, IL: Human Kinetics.
- The Fit Test*. (n.d.). Retrieved November 12, 2009, from Beachbody.com: <http://www.beachbody.com/text/products/programs/p90x/p90xFitTest.pdf>
- Weimar, W. (2009, June 1-30). Knee. Auburn, Alabama, United States of America.