Individual Deliverable #2 - Strength Testing & Measurement Team
Sensor Kit Selection
Jonathan Sampson

Selection of Force Measurement Method
Measurement Capacity and Accuracy
From initial research, we narrowed down the potential ankle force data capture methods to a few choices. These methods were pressure/force pad sensors, hand dynamometers or other piezoelectric force sensors, load cells, and strain gauges. We narrowed down our choices to pressure/force pads, piezoelectric sensors, and load cells.

Regarding pressure/force pads, one of the major challenges we had was determining how we would accurately measure ankle strength at the capacities of NFL athletes. Large force pads are not very common, and are therefore cost prohibitive in nature. When working with a $200 budget per test kit, large, fully integrated force pads are not an option. We then considered smaller force pads that would not cover as much area. From this, a key worry was that the athlete may have to make identical contact with the machine every time a measurement was to be taken. This would not be a problem if there was a fully integrated force matrix of individual cells, but this is not a very established method, and would require more time and knowledge than is currently available. Cheaper force pads simply did not have the raw force measurement capacity to provide accurate results at the levels of force generated by NFL athletes.

Piezoelectric sensors such as the Vernier Hand Dynamometer are generally less reliable at force sensing than other methods not involving materials that have as much “give” as piezoelectric materials. From personal experience, it was decently difficult to produce repeatable results with the hand dynamometer. Once integrated to an actual exercise machine apparatus with losses in pins, pads, and other structures, the uncertainty in measurement may be too great to ignore. On top of that, a single hand dynamometer unit is over $100, meaning that for both ankles, the kit would already eclipse our $200 budget.

Due to these insurmountable (re: this deliverable and the scope of the course) obstacles, we made the decision to all pursue testing apparatuses with load cells as the method of force capture. The variable in each test will be the loading condition defined by our testing rig.

Load Cell Utilization Research


When looking deeper into the Nordbord’s force measurement apparatus, we discovered that each ankle hook was attached to load cells positioned beneath the Nordbord surface (pictured right). This was a very clear clue that load cells would provide similar data output at the granularity that the Nordbord was already providing.

Furthermore, through prior experience in MIT course 2.671 - Measurement and Instrumentation, muscle force was measured very similarly. Load cells were used to measure force generated by the bicep. Anatomically, the upper arm and the lower leg have very similar muscle structures, so we assumed we could accurately measure muscle output with load cells, similar to the 2.671 Muscle Force Experiment.

Thinking ahead to potential integration with an exercise machine, it is apparent that the rollers where the ankles rest on the UCS Glute Ham Machine are stationary horizontal bars (pictured right). The padding may mitigate some of the force measurement, but it is likely that there is more fidelity of data if the "pulling" force is measured, instead of the contact force on the surface of the device. Therefore, integrating load cells into horizontal bars that experience upward pulling forces seem like the most easily transferable measurement apparatus. This is very close to the experimental setup of the 2.671 investigation (pictured left).

Practically, it is also considerably cheaper to purchase two load cells and the necessary electronic components and perform a voltage output to force calibration with a microprocessor. These factors contributed to the decision to use a load cell for force measurement.

Load Cell Specifications and Selection Rationale

Accuracy of Data for Sample Set

Reviewing the Nordbord NFL Hamstring Report helped us define the capacity for the force sensors. In 2019, the average hamstring strength for those tested was **458 N**, with the maximum strength being approximately **900 N**. To be able to accurately present data, we wanted to be appreciably clear of the average force, while also being able to accurately represent outliers in the sample set. We decided that we should use load cells with max force measurements of **~1000 N.**

The load cell of choice is the Pull Pressure Force S-type Load Cell (100kg configuration ≅ **980 N).** The load cell also has a sensitivity of ± 2.0 mV/V. We will be able to determine what this means regarding force once calibration occurs.

Size and Integration Potential

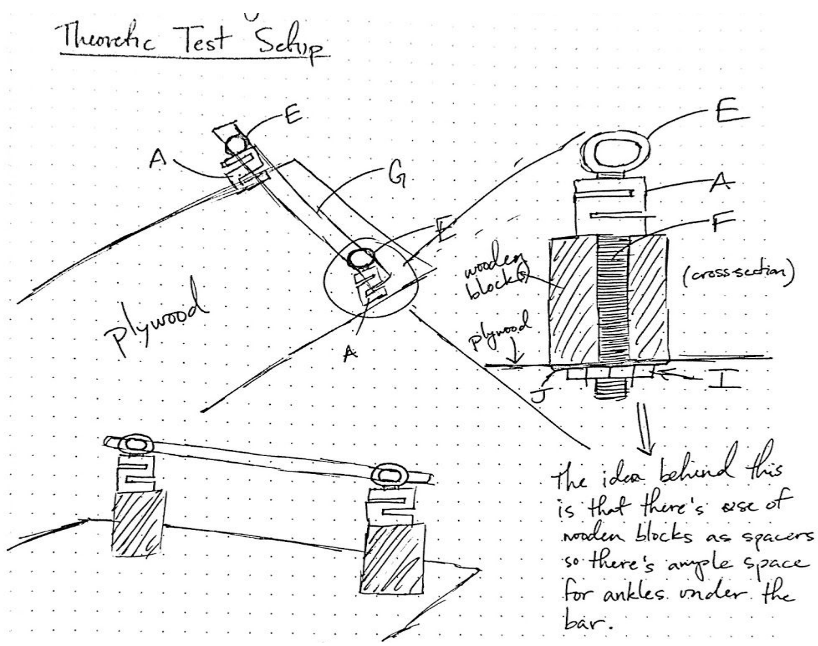
This load cell has a very small footprint that will allow it to be integrated easily into an exercise machine. It weighs 4.8 ounces, and is 3.9" x 3.1" x 2". The load cells can be easily encased with the electronics (likely on a PCB) in a very small attachment that can be mounted on a glute-hamstring machine. There will be little interference with the existing structure of the machine.

Integrating the load cell into the testing apparatus is also made relatively easy due to the threaded inputs at the top and bottom of the load cell, as well as the labeled wires representing signal, power, and ground outputs for the microprocessor.

Loading Condition and Test Setup

Test Setup

The apparatus I will use to test is very similar to that of the 2.671 experiment. It will feature two load cells and a horizontal bar, which will be the point of force application. However, instead of bolting the bar to the load cells, it will be fed through an eye ring bolt at each load cell. This is primarily due to lack of access to a machine shop. To fix the load cells to a stationary surface, they will be fastened through wood blocks and a sheet of plywood via a 250mm threaded rod and hex nut + washer. The sheet of plywood will (hopefully) be large enough for the athletes knees to also rest on it, so it will not leave the floor surface during testing. The wooden blocks primarily serve the purpose of acting as spacers so as to provide ample space for the ankles during testing. A rough sketch of the apparatus is below.

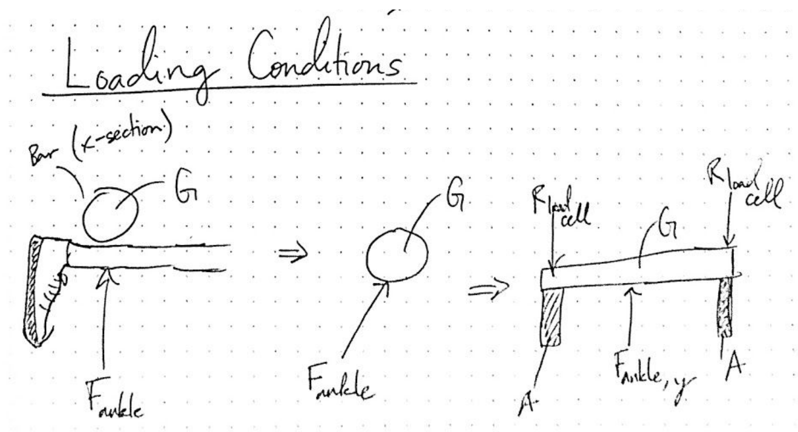


(Key: **A** - Load Cell, **E** - M12 Eye Ring Bolt, **F** - M12 Threaded Rod, **G** - 1" Aluminum Rod, **I** - M12 Hex Nut, **J** - M12 Washers)

Loading Conditions

With two load cells, the peak force measurement will simply be an aggregate of the individual forces experienced by each load cell. However, because there is only one rigid bar, asymmetry will not be measured by this test. For future iteration, we could potentially mirror this setup to have one for each leg.

This setup with multiple cells and the bar being rigidly in place allows for most of the force the bar experiences to be transferred through the eye ring bolts and onto the load cells. This setup was designed to mitigate any impacts of ankle force being dissipated in the materials due to slight deformations that may arise due to cantilevering of the beam if it is only supported at one end. A very simple analysis of this loading condition is sketched below.



The goal of this investigation is to determine the ease of data collection with this setup, and if it is any more or less accurate due to there being multiple load cells assigned to one force measurement. The investigation may also expand to testing various padding effects on force measurement.

The electronics portion closely follows the setup schematics detailed in this Load Cell Amplifier Hookup Guide.

Shopping List

These are the items for the sensor kit for the loading condition I would like to test:

- 2 Load Cells
- Arduino UNO Board
- Jumper Wires (Both M-M and F-F)
- M12 Eye Ring Bolts
- M12 x 250mm Threaded Rods
- 1” Aluminum Rod
- 2 Load Cell Amplifiers
- M12 Hex Nuts
- M12 Washers

Prices, quantities and shopping links are available on this spreadsheet: Individual Deliverable #2 Shopping List

Shipping Address: 14602 Shadewood Ct., Houston, TX 77015

Schematic Letter Designator	Item	Quantity	Unit Price	Total Price	Category/Purpose	Link
A	Load Cell (100kg)	2	$38.00	$76.00	Force Measurement	https://www.amazon.com/Pressure-Force-Ser
B	Arduino UNO Board	1	$23.00	$23.00	Electronics	https://store.arduino.cc/usa/arduino-uno-rev3
C	Jumper Wires M-M (20pcs)	1	$1.95	$1.95	Electronics	digikey.com/product-detail/en/sparkfun-electro
D	Jumper Wires F-F (20pcs)	1	$1.95	$1.95	Electronics	https://www.digikey.com/product-detail/en/spa
E	M12 Eye Ring Bolt (2 ct)	1	$9.99	$9.99	Hardware Rig	https://www.amazon.com/BULUSHI-Stainless
F	M12 Threaded Rod	2	$9.29	$18.58	Hardware Rig	https://www.amazon.com/uxcell-250mm-Threa
G	1" Aluminum Rod	1	$18.44	$18.44	Hardware Rig	https://www.amazon.com/RMP-Aluminum-Dia
H	Load Cell Amplifier	2	$9.95	$19.90	Electronics	https://www.sparkfun.com/products/13879
I	M12 Hex Nut (5 ct)	1	$8.99	$8.99	Hardware Rig	https://www.amazon.com/XunLiu-Stainless-St
J	M12 Washers (10 pcs)	1	$4.98	$4.98	Hardware Rig	https://www.amazon.com/Stainless-Steel-Flat-
			Total Price:	**$183.78**		