Lower Extremity Strength Tester (LEST)

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Abstract

It is common for women to experience a condition called pelvic instability during and after pregnancy. This can lead to pain and irritation in daily life. More seriously, it can lead to lower extremity weakness that can lead to further damage. Dr. Bryan Heiderscheit and Dr. Rita Deering have proved that this condition can be assessed by measuring the maximum voluntary contraction (MVC) of the lower extremities of a postpartum female performing a straight leg raise. Then they compared it to the MVC produced by an adult female who has not gone through pregnancy. However, the two have not been able to quantify their findings and need a device that can interface with existing force plates found in their lab and that can accurately measure the MVC of a postpartum adult female performing the predescribed task. The LEST (Lower Extremity Strength Tester) is an apparatus developed specifically for this task. It fixes directly to the existing force plates and allows the MVC of subjects to be recorded while following a strict testing method developed by the two doctors. By using the LEST, Dr. Heiderscheit and Dr. Deering hope to quantitatively measure the effect of pregnancy on lower extremity strength to create set points that can be looked upon in future clinical settings to determine if a subject is experiencing pelvic instability.

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I.Introduction

1. Motivation

Following childbirth, postpartum women experience a loss of muscle strength in the hip flexor (iliopsoas) and knee extensors (rectus femoris, quadriceps). This is due to the constant increased pressure on the muscles, thus causing abnormal stretching. These muscles also have an increased rate of fatigability. Frequently, women are often dismissed when describing these pains. During pregnancy and postpartum, women experience many physiological changes. Their abdominal muscles exert an increased stretch and inter-recti distance (Deering et. al, 2018). They also have hormones that influence the connective tissues, thus causing joint laxity (Deering et. al, 2018). Joint laxity is considered the looseness or instability of the joint (Eustice, 2017). Furthermore, the woman losses passive lumbopelvic joint stabilization (Deering et. al, 2018). This causes muscular stabilization from the abdominal muscles to overcome this loss (Deering et. al, 2018). Any external load applied to the woman in the pelvic region is severely debilitated. This very common problem in women is not researched extensively and more data is required. As a result, a device needs to be created to help collect force data from these muscularly impaired women. This device must quantitatively measure the force applied by the subject in the positive z direction (upwards) as accurately as possible. The device is required to be easily attachable to the force plate and supply a comfortable support to apply force. With no other competing designs, the product will not have any comparisons to products currently in market. By accurately collecting data from the force applied from the subjects post-fatiguing task, more data can be collected to help understand this recurring problem.

2. Problem Statement

During and after pregnancy, it is common for women to experience a loss of strength in the muscles of the pelvic girdle. This can cause serious pain and discomfort, and new methods are continually being researched to relieve women of this condition during their already challenging pregnancy. A device is needed that can assess a maximal voluntary contraction (MVC) of the hip flexor (iliopsoas) and knee extensor (quadriceps, rectus femoris) muscles during a straight leg raise task to assess the loss of strength, which can be a sign of pelvic instability, in the lower extremities of women both during and after pregnancy. The subject will first perform a fatiguing task with one leg, and will then lay inside of the apparatus quickly after completing this task. The fatigued leg will perform a straight leg lift, and the MVC produced by that leg will be recorded near the ankle of that leg. The leg that did not partake in the fatiguing exercise will press down into a separate force plate, and the MVC it produces will also be recorded. Therefore, our design must span the width of two force plates, allowing for both legs to be inside of it.

II. Background

1. Team Research

Pregnancy and childbirth create physical stress in many areas of the body. As the fetus grows, the abdominal muscles have to separate to allow the womb to protrude and weight distribution of the mother is altered. The physiological changes of childbirth and the stress of delivery contribute to weakened postpartum pelvic floor muscles. Pelvic floor muscles consist of multiple layers of musculature between the tailbone and sacroiliac joint which connects the spine to the pelvis (Therapeutic Associates Physical Therapy, 2018). These muscles contribute to sphincter closure and sexual function, as well as the function of supporting the spine, bladder, and internal organs. As a result, weakened pelvic floor muscles are associated with higher chances of pelvic organ prolapse; an occurrence in which internal organs "fall" to a lower location in the abdomen due to lack of support (Keane et al., 1997).

Pelvic bowl muscles (along with ligaments and other tissue) support the sacrum and ilium bones of the pelvis. When these muscles are weakened from childbirth, this distributes forces to where they wouldn't otherwise be which increases the chance of injury not only in the hip area, but also in the knees or ankles (Therapeutic Associates Physical Therapy, 2018). Evidence that pelvic muscles are bear relevance to other parts of the body is clear through studies of the Active Straight Leg Raise test (ASLR) in which the test has been shown to transfer loads between the legs and lumbosacral spine (Mens et al., 2001). The test is simply performed by raising one fully extended leg while supine.

For this study, participants will be asked to lie on their backs and perform a straight leg raise while their MVC (Maximum Voluntary Contraction) of the hip-flexors/knee-extensors is measured to determine pelvic instability. During this motion, the hip flexor, as well as the rectus femoris, sartorius, and tensor fasciae contribute to the motion of raising the leg. The knee extensor muscles (quadriceps and rectus femoris) contribute to stabilizing the leg (Thompson, 2017). For a detailed description of the testing process, see the testing procedure portion of the appendix.

To obtain an optimal design for the client, a few guidelines will be followed. The device will need to be moved between between two locations so our device should be light and easy to assemble and store. Also, the device must be able to withstand the strength of an adult women who will be pressing against it. During the test, the patients will need to perform a fatiguing task and soon after their MVC will be measured; therefore, the device will need to be set in place within 60 seconds after the fatiguing task. Since the patients are using all their leg force on the device, it is necessary that the push plate (where the patient's ankle presses) is soft enough to not cause them any pain. A more complete list of product design specifications can be found in the Appendix, section 1- PDS.

There are a few important dimensions that need to be taken into consideration for the dimensions of the LEST design. Primarily, the corner supports of the design much match up with the spacing between the the existing bolt holes in the force plate. The exact dimensions between these holes and the thread size have yet to be measured by Dr. Deering. An additional dimension that will be of importance is the height of the push plate. The average ankle circumference of an adult female is 20.14 (White, 1982) cm, and the average width is 4.7 (Alonso, 2016) cm. Using this information, the equation for the perimeter of an ellipse can be used to determine the length of the ellipse (distance from the front to the back of the ankle, above the foot). The calculation for this value are as follows:

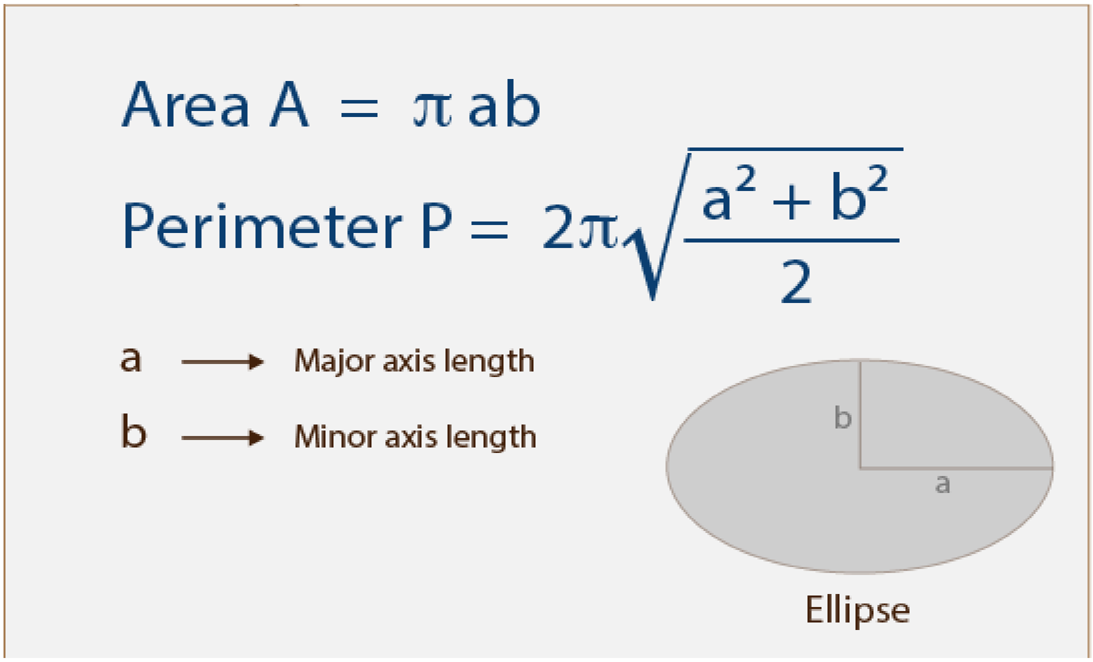

Image 1: *Equations for the perimeter of an ellipse.*

Known : P = 20.14 cm
b = 4.7 cm / 2 = 2.35 cm

a = sqrt(2*(P/2pi)^2 - b^2)
= sqrt(2*(20.14/2pi)^2 - 2.35^2)
= 3.88 cm
Therefore, the distance from back to front of ankle = 2*a = 7.768 cm

This dimension is of importance because the push plate will need to be at least this far from the force plate to allow the ankle to fit in between the two. However, this distance should not be much greater than the value of the average ankle height, as the forces produced by the lower extremity MVC should be as vertical as possible to ensure their accurate recording. Based on the previous math, the push plate needs to be at least 7.768 cm above the ground. Additionally, a few centimeters need to be added so the subject can easily move their foot underneath the push plate so that their ankle is beneath it.

2. Client Research Results

While the first LEST prototype has yet to be constructed, the client communicator, Dr. Rita Deering, has researched the correlation between the active straight leg raise and pelvic instability quantitatively. The LEST team has included this research and its findings here as they provide additional background information.

Dr. Deering, along with fellow researchers, used the active straight leg raise to assess the stability of the lumbopelvic muscles. Comparing the results of women up to twenty-six months postpartum with women who had never been pregnant allowed them to explore the effects of pregnancy on the lumbopelvic muscles. Postpartum women often experience pain such as lower back pain or pelvic girdle pain that could be a result of this loss of stability.

All of the women used in the study were free of other health problems that could have impacted the results of the test. Postpartum women completed their first test eight to ten weeks after delivery and their second test 24 to 26 weeks after delivery. Test subjects had to raise their leg twenty centimeters and hold for five seconds before lowering their leg. They then rated the difficulty of that task on a scale of zero to five with five being unable to lift their leg and zero being not difficult at all. Pressure was applied to the region if the score reported was higher than a zero. If the difficulty decreased, then lumbopelvic instability was reported. Then participants performed the active straight leg fatigue test in which their leg was raised to twenty centimeters and held. Failure occurred when an air bladder under their lower back changed pressure by twenty or more mmHg or their leg dropped below ten centimeters. Initially, 23% of the control and 37% of postpartum women tested positive for instability. Later tests reported 12.5% and 44% respectively. The fatiguing task showed a faster failure time for postpartum women than the control groups. No difference was found between the time to failure of those testing positive for active straight leg initial test and those who tested negative (Deering et al., 2018).

3. Discussion

From the researchers at Marquette University, it was found that women postpartum test positive for pelvic instability. The data from their research was all qualitative and differed between tests. An issue with this data is that the results differ; one way to develop more accurate and consistent results would be by producing quantitative data. The Lower Extremity Strength Testing device should allow for those results. Ultimately, the LEST will allow women to press upward (10-20 cm) into a beam that will essentially measure the patient’s force. This force can be analyzed to receive the maximum voluntary contraction (MVC) of the hip flexor muscles.

For the device, there are sources of error that will need to be taken into consideration. One source of error would be regarding the material that the patient will press their ankle against. This material should not be so hard that it induces pain and alters the amount of force the patient is willing to apply. Another important factor is recovery time. It is required that the patient is able to quickly position themselves in the device and perform the task as quickly as possible. The longer it would take the more time the muscles have to recover which would impact the overall force. Lastly, since the device will be screwed into force plates on the ground it should be taken into account any dipole moments. This would occur as the patient presses against the device and causing the device to lift or bend at the ends into the force places creating an increased or decreased force.

III. Preliminary Designs -

After considerable research and collaboration with Dr. Deering on the testing procedure, the LEST team developed three feasible design alternatives.

1. The Jungle Gym

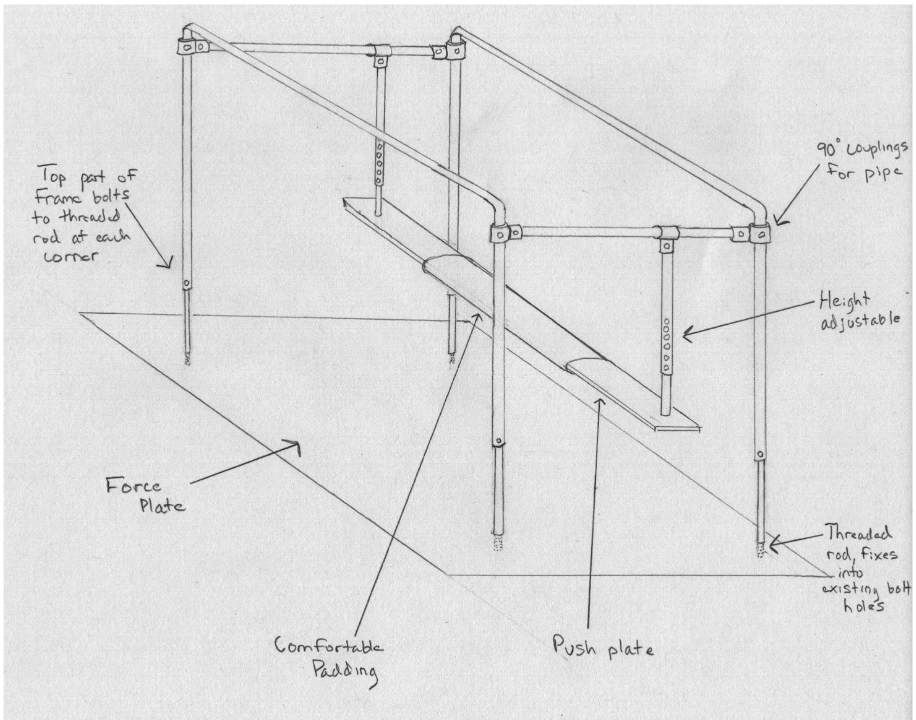

Image 2: *The Jungle Gym design idea.*

The Jungle Gym design is comprised of a simple frame network that consists of varying sizes of aluminum tubing and a push plate that hangs in the middle of the network that provides an ideal surface for the client to push against. There are four corner posts with threaded ends that fix directly into the bolt holes and then the rest of the frame assembly can be set upon the corner posts and pinned in place. All pieces are fixed together with 90 degree tube couplings and will be bolted in place to them. The push plate will hang down from vertical supports and will be fixed to a piece that is smaller in diameter than the inner diameter of the support tube, allowing for the push plate to be height adjustable.

2. The Box

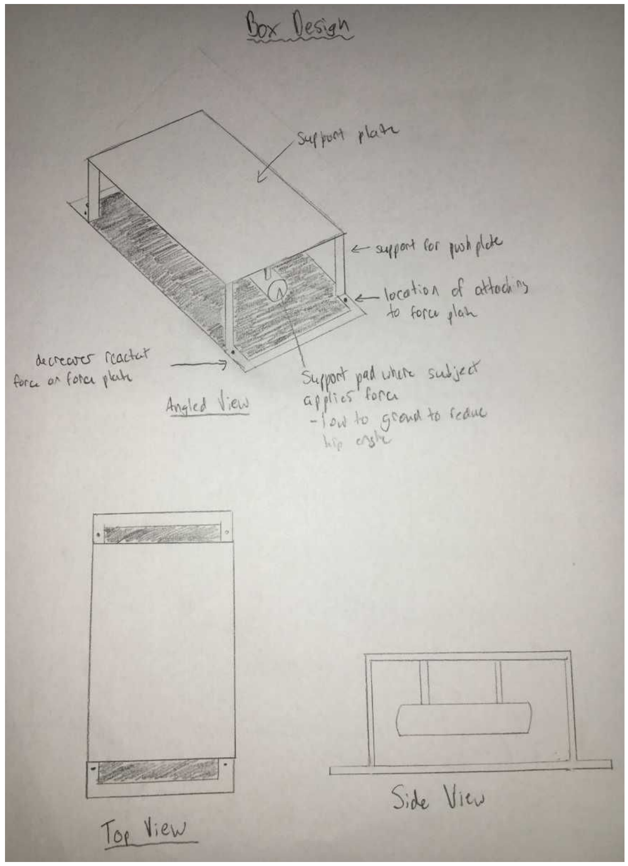

Image 3: *The Box design idea.*

The Box design features a plate that rests on top of four corner supports. These supports have a "foot" at the bottom that is perpendicular to the vertical portion of the support, and each foot has a hole drilled through it for a bolt to fix into the existing bolt holes of the force plates. A padded bar hangs down from the top plate and provides a surface for the subject to push against. This bar is relatively low, ensuring that the force created by the subject is as close to vertical as possible. This will aid in ensuring the accuracy of the data collected during testing.

3. The Rubber Hose

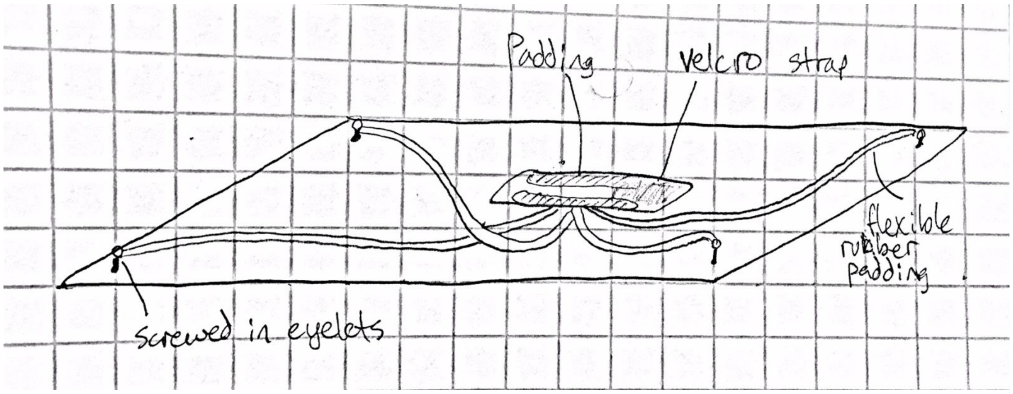

Image 4: *The Rubber Hose design idea.*

The Rubber Hose design idea features four lengths of hose that are tied onto eyelets screwed into the four existing bolt holes in the force plate on one end. At the other end, each length of rubber hose fixes to a leather harness with a velcro strap that will fix directly to the ankle of the subject during testing.

IV. Preliminary Design Evaluation

1. Design Matrix

Design / Criteria	Design One - Jungle Gym	Design Two - The Box	Design 3 - Rubber Hose
Ability to Accurately Measure MVC (30)	5/5 30	4/5 24	2/ 5 12
Quickness of data collection after fatiguing task (25)	4/ 5 20	4/ 5 20	5/5 25
User Comfort (15)	4/ 5 12	4/ 5 12	4/5 12
Ease of Fabrication/Assembly (15)	3/ 5 9	3/ 5 9	5/5 15
Aesthetics (5)	5/5 5	4/ 5 4	1/ 5 1

Cost (5)	3/ 5 3	3/ 5 3	5/5 5
Safety (5)	5/5 5	5/5 5	3/ 5 3
Total (100)	84	77	73

Figure 1: *The LEST design matrix, showing overall scores for the three proposed designs.*

2. Justification of Criteria and Weight

Ability to accurately measure MVC-

Accuracy received the highest weight because the effective functioning of the design is of the utmost importance. This design will be used in actual research that will be published by university faculty, so it must have a high degree of accuracy to ensure the validity of the results of the research. The Jungle Gym design scored highest (5/5) because it is fixed vertically to the force plate. The Box, in contrast, was fixed with bars connecting flush with the force plate. These bars could transfer non-vertical force from one support to another or torque into the force plate. The Rubber Hose design allowed for a multitude of horizontal forces.

Quickness of Data Collection After Fatiguing Task-

It is imperative that the MVC of the subject is able to be recorded quickly after completing the fatiguing task to prevent their muscles from recovering and skewing the data. Additionally, the patient should easily be able to place their legs within the device without struggle. The Rubber Hose scored the highest in this category because it will be fixed to the subject during the duration of the test, whereas the subject will have to move their leg into contact with some surface of the other two designs to initiate data recording.

User Comfort-

As a patients MVC is being measured, they should not endure any pain that could affect their results. This would likely be encountered between the surface that comes into contact with the ankles, where the MVC is measured. This surface should not be so hard that it causes discomfort, but should also not be so soft that it absorbs the force of the MVC and skews the data. Each of the designs received the same score in comfort because each design incorporated padding to allow the subjects to be comfortable while performing the straight leg lift.

Ease of Fabrication/Assembly-

Fabrication of the design should be completely within our ability. Also, the device needs to easily attach to the force plate in a manner that any administrator of the task can accomplish be easily removable for transport to different facilities. The Rubber Hose scored the highest because for fabrication it didn't require a lot of material, and nothing that needed to be built together. As for assembly, the only assembly required would be to screw into the holes on the plates and a velcro strap for the patient's ankle.

Aesthetics-
Aesthetics received one of the lowest weighted criterias due to it not having any impact on the patient's well-being or the results from the device. However, the final design should still look professional, as it will be used in professional research. The jungle gym was scored the highest in this category because it is not as bulky as The Box design did not look as professional as the other designs.

Cost-
The client offered a budget of 1000$ and this will be extremely sufficient for any design. For this reason, the cost weight was lower. None of the designs should reach this overall cost, but the rubber hose obviously features the fewest and the most simple materials, so it scored the highest in this category.

Safety-
The safety of the client and the test subject is an important aspect of any design. It is assumed that any design considered will meet a certain standard of safety. The design will likely be stationary and will not in any way alter the subject, so there are not many safety concerns involved. The Box and the Jungle Gym design scored the highest in this category because the subject's movements are relatively constrained, whereas the Rubber Hose design would allow for the subject's lower body to move in all directions, which presents an inherent safety concern.

3. Proposed Final Design:

The jungle gym received the highest score overall. Its accuracy and speed of data collection, aesthetics, and patient comfort were some of the highlights of the design. However, after further team discussion, it was realized that some features were still missing despite it's high scoring. They include:

- A feature that allows the push plate to "fold up" so that it can be moved out of the way while the subject performs their fatiguing task.
- A rest for the foot that isn't recording an MVC so that it doesn't push against the force plate and disrupt the accuracy of data collection.

After adding these components to the existing Jungle Gym design, the final design was completed and appears as follows:

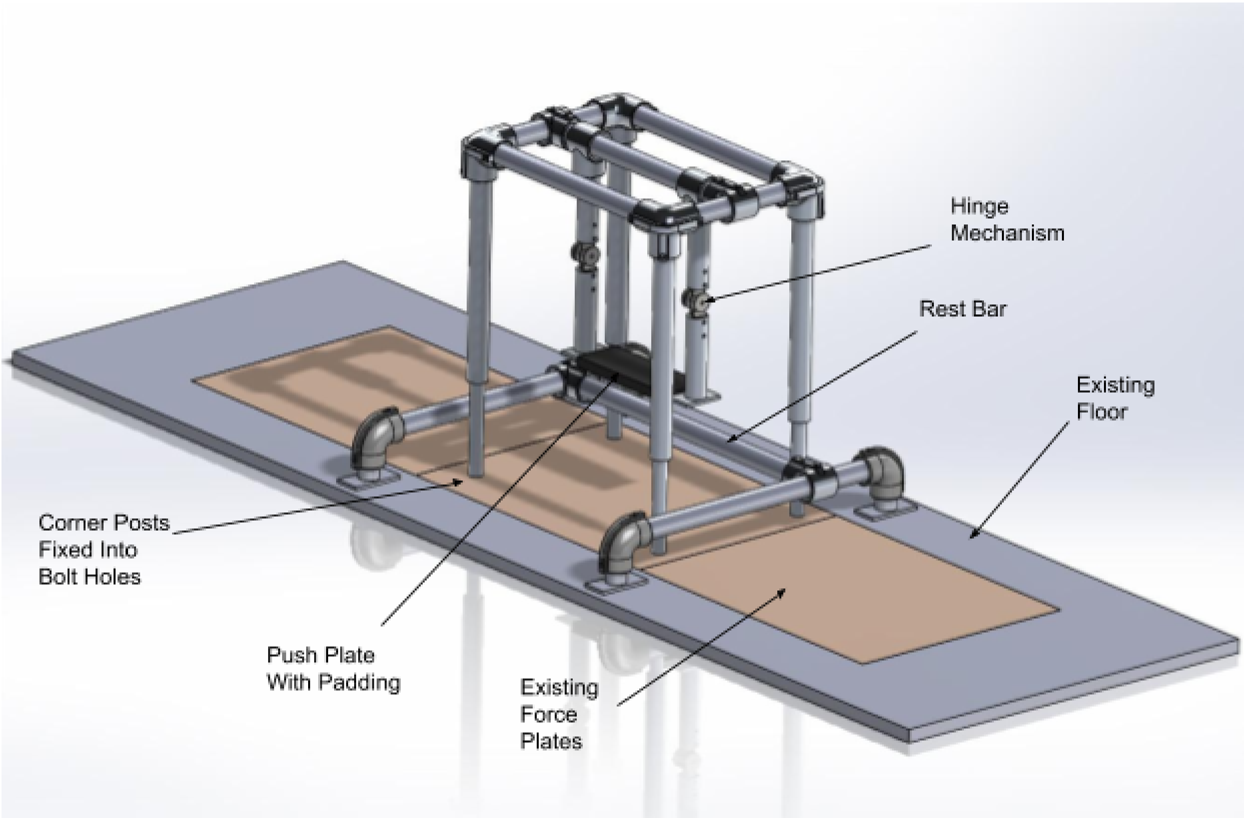

Image 5: *Isometric view of the proposed final design.*

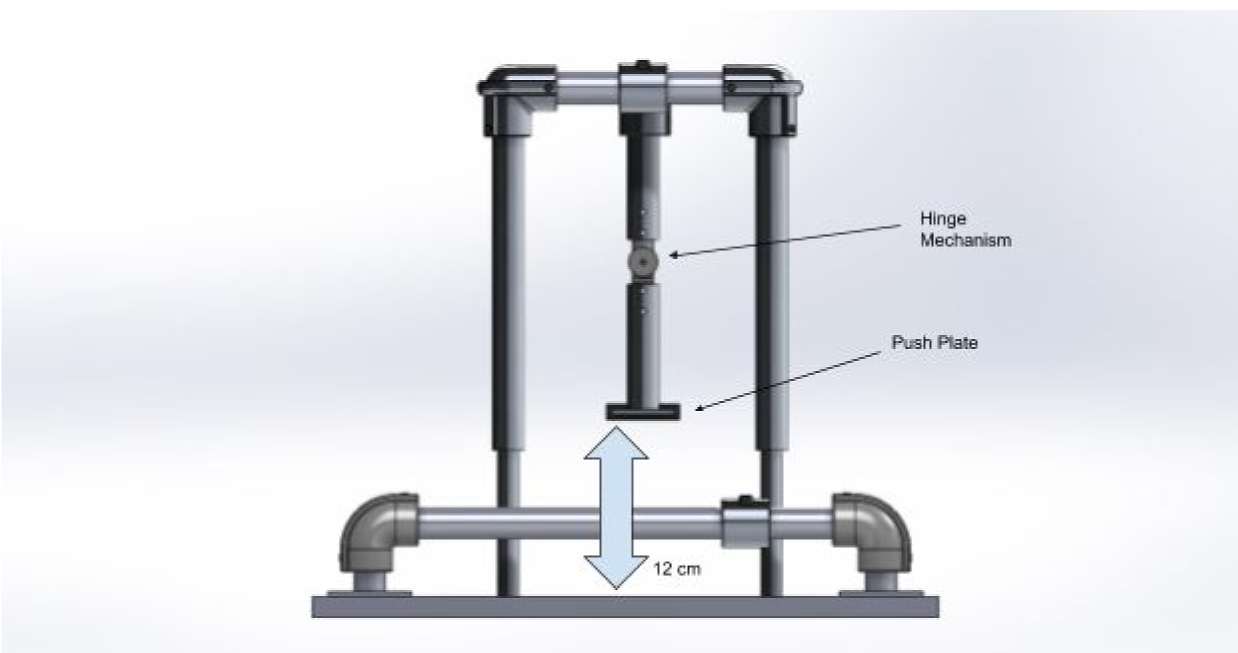

Image 6: *Right side view of the proposed final design.*

This design is much like the original Jungle Gym, but it includes the two main features that were listed above. A hinge mechanism that is adjustable when a button is pushed in will be placed between the two vertical pieces that support the push plate. Additionally, a rest bar has been added to support the foot not producing an MVC during testing. As can be seen in the image above, this assembly is entirely separate from the Jungle Gym apparatus and does not in any way come into contact with the force plates. This is because any downward pressure on the force plate from the foot and leg not in use would disrupt the accuracy of the data generated by the MVC of the other leg. This would have been an issue if the rest bar were attached to the Jungle Gym.

V. Fabrication/Development Process -

1. Materials

For this project, the frame will consist mostly of aluminum tubing and solid bar. Everything will be fixed together with variously shaped connecting joints, which will hold the frame pieces in place with set screws. The rest bar will be fixed on each end with a rail, and each rail will be joined to a vertical support with a connecting joint, and this vertical support will bolt into a piece of aluminum bar. The hinge joint that allows the push plate to be moved out of place is locked and unlocked by the pushing of a button. This will be bolted in place in between two vertical supports. A detailed list of the materials used for this project and their cost can be found in the Appendix, section 2- Materials List.

2. Fabrication Methods

Very little modification will have to happen to the parts that will be ordered to create our final design. The tubing, rounds, and bars will come in long lengths that need to be cut to length and their edges need to be broken. Some holes will have to be drilled in particular parts (namely the vertical supports for the push plate so that the hinge mechanism can be fixed in place). Additionally, the four corner posts will have to have their ends turned down and threaded to the appropriate size to fit the existing bolt holes in the force plates. After completing all of the necessary modifications to the ordered materials, the individual parts will be assembled using the connecting joints as depicted in the assembly image in the Proposed Final Design Section. A complete list of the fabrication processes needed to complete the LEST can be found in the Appendix, section 3- Fabrication Methods.

VI. Conclusion

For this study, participants will be asked to lie on their backs and perform a straight leg raise while their MVC (Maximum Voluntary Contraction) of the hip-flexors/knee-extensors is measured to determine pelvic instability. The device used will need to be light, quick and easy to assemble, comfortable, and able to withstand the strength of an adult female who will be pressing against it. We decided that the Jungle Gym design is the best because it scored highest on the design matrix indicating that it matches the design requirements closer than the alternatives. A leg rest and hinges for the push plate will be added to create an optimum product. One alteration that will likely be made beyond these additions is an adjustable push plate allowing the design to be adjusted to each test subject. Moving forward, the next step includes consulting with our client to ensure we have suitably met her design preferences. Assuming this is the case, parts will be ordered and the prototype fabrication process will begin.

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VIII. Appendix

1. **PDS**

LEST (Lower Extremity Strength Tester)

Product Design Specifications
Client: Dr. Bryan Heiderscheit and Dr. Rita Deering
Team: Sam Parmentier, Dan Wildner, Kaitlin Lacy, Brittany Glaeser, Noah Nicol
10/7/2018

Function:

During and after pregnancy, it is common for women to experience a loss of strength in the muscles of the pelvic girdle that can lead to pelvic instability. This can cause serious pain and discomfort, and new methods are continually being researched to relieve women of this condition during their already challenging pregnancy and the busy months after. Currently, to determine if a patient has pelvic instability, a doctor has them perform a straight leg raise and rate the difficulty of doing so on a scale of 0-5. If the patient gives a rating of anything other than 0, the doctor then pushes the hips towards each other at the side and has the patient try the straight leg raise again. If the extra pressure from the doctor makes the straight leg lift easier, this is indicative that the patient may have pelvic instability. One of the clients, Dr. Rita Deering, has performed comprehensive research that concluded that pregnancy has a significant impact on the strength of the pelvic girdle muscles, but is now trying to quantitatively analyze the extent of the effect it has. Therefore, a device is needed that can assess a maximal voluntary contraction (MVC) of the hip flexor (iliopsoas) and knee extensor (quadriceps, rectus femoris) muscles during a straight leg raise task to assess the loss of strength in the lower extremities of women both during and after pregnancy as a result of pelvic instability. This device will be directly affixed to pre-existing force plates that will allow for the measurement of this MVC during testing.

Testing Procedure:

While laying down with their feet inside this device, the subject will first perform an unassisted leg raise with one leg to fatigue it, and the other leg will remain on top of a force plate to record how much force it pushes down with. This fatiguing task will be performed until failure, which is achieved once the foot drops beneath 10 cm or excessive lumbopelvic motion occurs (measured by an air bladder underneath their lower back). Then, the fatigued leg will immediately perform a straight leg lift, and the MVC produced by that leg will be recorded near the ankle of that leg. The leg that did not partake in the fatiguing exercise will rest on a bar separate from the device so as to not skew the MVC being recorded. This process will then be repeated with the opposite leg on a separate day.

Client requirements:

- Portable between UW Health Research Park Clinic and Badger Athletic Rehabilitation Training Center
- The device must be strong enough to withstand an MVC from an adult female performing a straight leg lift.
- The device must be in place and ready to use within a minute after subject's fatiguing task to prevent muscle recovery.
- Comfort of the test subject must not limit the amount of force able to be produced.
- A budget of $1000 must be kept.
- The device must be designed so that it can be used when the patient is supine (lying on the floor).
- The subject should not be able to hold onto the device in any way, and secondary help from a doctor or different test subject should not be required to hold the device in place.
- Force plates will be provided for measuring the MVC's.
- The surface of the design that the subject will press against with their ankle must not be uncomfortable to the point of causing pain, but must also not be too soft as to absorb the force of the MVC.
- The device must be conducive to the specific testing procedure detailed above.

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements:

- The device must attach to a force load plate via four bolts to obtain a vertical force reading of the MVC of a female leg.
- The device will be used frequently in UW-Health Research Park as well as other lab setting locations during the lifetime of the research project.
- Able to withstand the force of a straight leg raise at maximum effort for an adult female
    - Muscles involved: iliopsoas, quadriceps, and rectus femoris.
- The device must help to consistently and accurately measure the force of a lower body MVC (the force plate will be doing the quantitative measuring).

- There must be adequate room within the device for the fatiguing task to be performed.
- All portions of the device must be fully compatible with the specific testing procedure detailed above.

b. Safety:

- Comfortable for patients to exert force without pain
- Able to easily accommodate patients of varying sizes, with the lower body size being of particular concern.
- Sturdy enough to avoid collapse and/or fracture from a lower body maximal muscle exertion of an adult female.
- No sharp or rough edges or protruding parts that could injure subjects as they use the device or the clients as they put the device in place.

c. Accuracy and Reliability:

- The device needs to contribute to an accurate reading from the force plate over multiple tests with varying patients (within 5% accuracy). This may require the ability to adjust on a per patient basis (in terms of height of apparatus).
- The device should limit the area the patient can be situated in order to maintain the position of the straight leg lift.
- A separate support must be included for the foot of the leg not producing the MVC.
    - This support must not be attached to the device, as this would skew the accuracy of the MVC being recorded.

d. Life in Service:

- Needs to be easily transported from UW-Health Research Park Clinic to Badger Athletic Rehabilitation Training Center.
- Needs to be available at any time of the day for extended periods of time. The number of cycles of MVC measuring is still yet undetermined.

e. Operating Environment:

- The device will be used and stored in a clinical setting.
- The largest chance for damage will likely occur during transport between clinics or while under stress from force applied by patient.
- Possible causes of failure could arise when subject is trying to quickly get inside the apparatus and their leg/body collides with the apparatus in some way.

f. Ergonomics:

- Must be strong enough to easily withstand maximum contortion of hip flexor and knee extensor muscles of an adult female.
- Must allow a wide range of adult females to place feet into device

    - The interacting force bar needs to have enough space to accommodate a wide range of adult female ankles

g. Size:

- The apparatus must be wide and high enough to comfortably fit the lower legs/feet of any size adult female between its frame.
- The frame of the device will largely be sized based upon the layout of already existing holes in the force plate. These will be measured during the next client meeting.

h. Weight:

- The maximum weight of the device is 50 lbs, as it will need to be lifted and transported by one person between locations.
    - Ideally, the design will weigh much less than this.

i. Materials:

- No materials restrictions have been placed on this project as far as incompatibility with other equipment being used during the testing procedure.
- The frame will likely be comprised of extruded aluminum.
- The part of the device interacting with subject needs to be comfortable but not so soft that it absorbs the force of their MVC. A harder rubber material will likely be used.

j. Aesthetics, Appearance, and Finish:

- All seams, joints, and welds should be neat and aesthetically pleasing.
- There should not be any unfinished edges or contact points.
- No extraneous materials should be hanging down, protruding from, or in any way seen on the device.
- The device's appearance should be comparable to the professional exterior of exercise equipment.

2. Production Characteristics

a. Quantity:

- One LEST will need to be produced.

b. Target Product Cost:

- A budget of $1000 dollars for this project has been set. Other competing designs have a cost of around $1000 dollars, so it would be preferred that our design does not reach that cost level.

3. Miscellaneous

a. Standards and Specifications:

- No FDA approval is required.

- Some lab standards may need to be met based on the policies of our client's lab environment.

b. Customer:

- This design is not intended for commercial sale. For concerns of subjects utilizing the designs, please look below to "patient related concerns."

c. Patient-related concerns:

- Patient data confidentiality must be considered. The numerical value of MVC's of patients will be recorded, which is private information between the patient and the doctor performing tests.
- This device will be used for pregnant and postpartum women, so comfort is a major concern.
    - Subject must easily be able to position themselves inside the frame of the apparatus and perform the test quickly after completing a fatiguing exercise.
- The testing of the apparatus involves creating a maximum force with certain muscles, so we want any surface of the device that a subject is pressing against to not cause them any pain or discomfort.

d. Competition:

2. MICROFET 2 MANUAL MUSCLE TESTING (MMT) HANDHELD DYNAMOMETER - $1,054
    a. The Microfet 2 is an ergonomically-designed dynamometer that accurately measures the force produced by a certain muscle.
3. Doctor's test-
    a. A simple test that doctors use to measure if a patient has pelvic instability is to press against the sides of their hips and ask if that makes it easier for them perform the leg lift. If they say it does, they are considered to have pelvic instability.
4. Training of whole leg waist abdominal muscle of lying on back power and test system - CN # 201520291327
    a. This patent seemed to describe an apparatus that measured forces created similar to the ones in our testing procedure.

2. Materials List

TO BE ORDERED:					
Part Number	Description	Vendor	Cost	Qty	Subtotal
1258A120	Incremental Angle Position Hinge	McMaster Carr	$123.70	2	$247.40
4698T114	3-Way 90 Degree Elbow Connector for 1.5" Pipe	McMaster Carr	$20.38	4	$81.52
4698T170	Tee Through-Hole Connector for 1.5" Pipe	McMaster Carr	$13.64	6	$81.84
4698T340	90 Degree Elbow Connector for 1.5" Pipe	McMaster Carr	$17.03	4	$68.12
8974K13	6061 Aluminum Round, 1 " DIA x 3' Length	McMaster Carr	$16.85	1	$16.85
8974K18	6061 Aluminum Round, 1" DIA x 3' Length	McMaster Carr	$33.95	1	$33.95
89965K32	General Purpose ALuminum Tubing. 1.5" OD	McMaster Carr	$72.33	3	$216.99
8975K71	6061 Aluminum Bar, .25" thick x 2" Wide, 2' Len	McMaster Carr	$9.07	1	$9.07
8975K87	6061 Aluminum Bar, .25" thick x 3" Wide, 2' Len	McMaster Carr	$15.09	1	$15.09
75315A53	Foam Mounting Tape, .194" Thick x .5" Wide ' 4	McMaster Carr	$9.75	1	$9.75
				TOTAL	$780.58
FINAL PARTS AFTER FABRICATION					
Part Number	Description	Vendor	Cost	Qty	Subtotal
1258A120	Incremental Angle Position Hinge	McMaster Carr	$123.70	2	$247.40
4698T114	3-Way 90 Degree Elbow Connector for 1.5" Pipe	McMaster Carr	$20.38	4	$81.52
4698T170	Tee Through-Hole Connector for 1.5" Pipe	McMaster Carr	$13.64	6	$81.84
4698T340	90 Degree Elbow Connector for 1.5" Pipe	McMaster Carr	$17.03	4	$68.12
	1" DIA Aluminum Round- 8.5" Length			4	0
	1.5" OD Aluminum Tube with 1" ID, 16" Length			4	
	1.5" OD Aluminum Tube with 1" ID, 18" Length			2	
	1.5" OD Aluminum Tube with 1" ID, 12" Length			2	
	1.5" OD Aluminum Tube with 1" ID, 22" Length			2	
	1.5" OD Aluminum Tube with 1" ID, 24" Length			1	
	1.5" OD Aluminum Round, 6 " Length			4	
	2" x 4" x .25" Aluminum Bar			4	
	3" x 13.5" x .25" Aluminum Bar			1	

3. Detailed Fabrication Process

The following parts are final sized parts that need to be fabricated for the assembly of the LEST apparatus:

Part Description			Quantity
1" DIA Aluminum Round- 8.5" Length			4
1.5" OD Aluminum Tube with 1" ID, 16" Length			4

1.5" OD Aluminum Tube with 1" ID, 18" Length			2
1.5" OD Aluminum Tube with 1" ID, 12" Length			2
1.5" OD Aluminum Tube with 1" ID, 22" Length			2
1.5" OD Aluminum Tube with 1" ID, 24" Length			1
1.5" OD Aluminum Round, 6 " Length			4
2" x 4" x .25" Aluminum Bar			4
3" x 13.5" x .25" Aluminum Bar			1

The methods for creating each part will be described in detail in the order they are presented above:

1” DIA Aluminum Round- 8.5” Length- x4

1. On drop saw, cut 2” length into four 8.75 “ pieces.
2. On lathe, face one end of each piece and turn down to ⅜” DIA with a depth of .5”.
3. On mill, mill each part to finished length of 8.5”.

1.5” OD Aluminum Tube with 1” ID, 16” Length- x4

1. On drop saw, cut 6’ Length into four 16” pieces, using a stop for accuracy.
2. Break sharp edges.

1.5” OD Aluminum Tube with 1” ID, 18” Length- x2

1. On drop saw, cut 6’ Length into two 18” pieces, using a stop for accuracy.
2. Break sharp edges.

1.5” OD Aluminum Tube with 1” ID, 12” Length- x2

1. On drop saw, cut remainder of 6’ Length into two 12” pieces, using a stop for accuracy.
2. Break sharp edges.

1.5” OD Aluminum Tube with 1” ID, 22” Length- x2

1. On drop saw, cut 6’ Length into two 22” pieces, using a stop for accuracy.
2. Break sharp edges.

1.5” OD Aluminum Tube with 1” ID, 24” Length- x1

1. On drop saw, cut remainder of 6’ Length into one 24” piece.
2. Break sharp edges.

1.5” Aluminum Round, 6” Length- x4

1. On drop saw, cut 2’ length into four 6” pieces.
2. On lathe, face off one end of each piece and drill a 25/32” hole to a depth of 1”.
3. On mill, mill each piece to finished length of 6”.
4. On mill, drill two ¼” clearance holes on one end of each piece, with the first hole being 5/16” away from the end (on center) and the other hole being 1” away from the first hole (on center).
5. Break sharp edges.

2” x 4” x .25” Aluminum Bar- x4

1. On drop saw, cut 2’ length of bar into four 4” long pieces.
2. Break sharp edges of each piece.
3. On mill, drill a and tap a hole in the center of each piece for a ⅜-16” screw.

3” x 13.5” x .25” Aluminum Bar- x1

1. On drop saw, cut 2’ length into one 14” piece.
2. On mill, mill each end down, milling down to the finished length of 13.5” while milling down the second end.
3. Drill two clearance holes for a ⅜-16” bolt with 10.5” in between them. The holes should be centered along along both the width and the length of the piece.