Physical Function Testing Apparatus for Monkey

Biomedical Engineering Design 200/300

Team Members: Heather Barnwell (BWIG), Ben Horman (BSAC), David Luzzio (BPAG), Ben Myers (Team Leader), Ben Ratliff (Communicator)
Client: Dr. Ricki Colman
Advisor: Dr. Aaron Suminski

Abstract

Rhesus monkeys have long been used as models for scientific research for due to their similar anatomy to humans [1]. One similarity that has been used for research is the motor function of these animals. Research has been done to compare basic motor function to neurological stimuli [2] and to evaluate basic grip strength [Bury]. Although these efforts have been effective, there currently is no method for testing the strength for any large muscle group. Large muscle groups, such as those on the arms and legs, are more effective to test as they are most often the muscle groups that are biopsied by researchers. Due to this, there is a need for an apparatus that is capable of evaluating these major muscle groups maximum strength in a safe and effective way. Therefore we have designed a novel Sliding Cage Apparatus, which can evaluate the maximum strength of Rhesus monkeys' major muscle groups in the most safe method possible. The design will be fabricated and tested on human forces before being tested on an experimental group of subject Rhesus monkeys.

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Introduction

Problem Statement

In studying the effects of diet on the macaque monkey, muscle function and strength give important data to the aging of the test subjects. Currently, muscle mass can be measured; however, information on the animal's muscle strength lacks. An apparatus to motivate the monkeys to test their strength, exercise their upper and lower body, and give feedback, isn't available in the primate center on the UW campus. The goal of this project is to develop a method for testing the physical function of the hind and forelimbs of a macaque monkey that will be durable, able to be sanitized, and safe for the animals.

Background

Rhesus Monkey Physiology

Humans and monkeys share a fairly similar anatomical structure, and specifically rhesus macaque monkeys are used in studies to connect to the general scope of human and nonhuman primate health (1). Rhesus macaques are quadrupedal with opposable toes, so they tend to use their feet for gripping as well as their hands. This increased range of motion provides more possibilities for muscle movements, but offers more challenges in finding ways to isolate the muscle groups.

To obtain muscle mass data, biopsies are often taken from the quadriceps because of the muscle group's large amount of tissue and relatively quick recovery time. According to Dr. Colman, scientists choose to avoid the core when taking biopsies because this would have more complications and further inhibit the animal's recovery.

Competing Designs

In assessing monkey strength, numerous competing devices follow two common practices: a reward, often in the form of food, is provided upon completion of a specific motion against a certain resistance, and resistance behind that motion is increased per trial to reach maximum strength. Motions utilized by these devices typically include gripping and pulling a weighted-sled. Once a maximum force is observed, it is divided by the monkey's weight to normalize measurements among separate individuals. While applicable to and optimal for many studies, these devices are not ideal in light of Dr. Colman's preferences for this project.

The first competing design, implemented by Bury SD et al. in a study to understand grip-behavior by normal and neurologically-impaired squirrel monkeys, is a small force transducer within a bisected aluminum cylinder. As a monkey squeezes the cylinder, surfaces of the two aluminum halves contact each other and allow the force transducer to collect data (2). The grip-cylinder is mounted to a three-axis sliding frame by a universal joint, which prevents normal and moment forces imparted by body-parts other than the hands from altering force data (2). Monkeys are provided a reward upon each squeeze at a specified force. This design is advantageous in its simplicity and intuitiveness to the monkeys. However, it is not ideal for Dr. Colman's research, which aims to assess leg strength rather than forearm strength.

The second competing design, implemented by Bozek et al. in a study to understand the evolutionary divergence of human, chimpanzee, and macaque monkey strength, is a sled with adjustable weight that is dragged against an even surface by a rope. Between the sled and rope is a linear force gauge, which measures the maximum force produced while pulling the sled during a specific trial (3). Using its entire body, a chimpanzee or macaque monkey pulls the sled towards its enclosure to receive an attached reward (3). This design is advantageous in its simplicity, intuitive use, and cost-effectiveness. However, it does not encourage a standard motion to produce a force -- allowing for many pulling strategies -- and therefore does not produce accurate data. It is not ideal for this project in that it does not isolate leg movement.

Client Information

Dr. Colman's research in the Wisconsin National Primate Research Center concentrates on the impact that caloric intake has on the aging process of nonhuman primates. By analyzing strength in numerous rhesus monkeys with varying diets, she will be able to examine long-term effects (4).

Design Specifications

The design for an apparatus that tests the strength of rhesus monkeys must be fully functional, safe, and durable, considering the device will work directly with the animals. Since there are multiple regulations in place to guarantee that animals participating in research remain unharmed, this design must be safe whether the monkey is using it in its intended manner or not. There cannot be any exposed wires or sharp edges, and the chances of escape must be minimized during set-up as well as during use. The device must also be easily sanitized and rust resistant like all equipment in the primate center. One person should be able to set up this device, which restricts the weight and size of the design, and it must be compatible with multiple cage designs. A reward system must also be in place to positively reinforce the animal. This system, coupled with training that the client will provide, should ensure maximum effort from the monkey and the most accurate results. The apparatus must be simple enough that the monkey can perform the required maneuvers after minimal training.

Design

Considered Designs

Stationary Deadlift

The first considered design consisted of a box that has a force gauge on the inside that is attached to a handle, which is located on top. The apparatus would be attached to the bottom of the cage. While the device is being set up, the monkey would need to be moved to a temporary cage. This device would test the monkey's strength by having the monkey pull upwards on the handle. In order to test maximum strength, the minimum force threshold required to get a reward would be gradually increased. This would motivate the monkey to pull with maximum strength. Due to the motion of movement by the monkey, the apparatus would test both upper and lower body strength. Although the primary focus is lower body, we believe that if the minimum force required for a reward was great enough, the monkey would incorporate its lower body as much as possible. This would still allow for the testing of the maximum strength of the lower body.

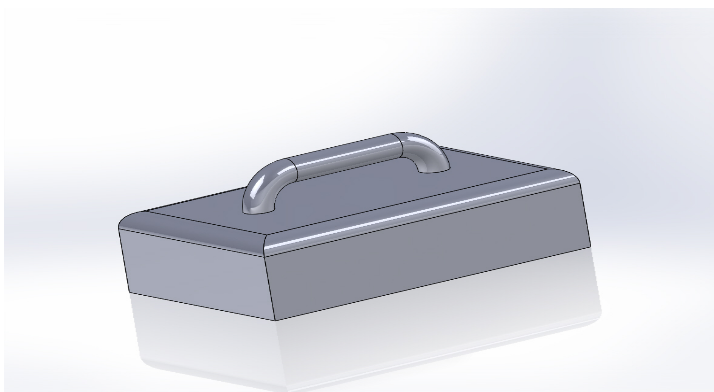

Figure 1: The image above shows the SolidWorks design for the stationary deadlift design.

Push Plate

The second design considered would utilize a feature of the cage called a squeeze plate. The squeeze plate involves a plate located at the back of the cage, which is attached to bars that come out past the front of the cage. When the bars are pulled outwards, the squeeze plate moves towards the front of the cage. This forces the monkey towards the front of the cage as well, and allows the researcher to more easily take various samples from the monkey. For this design, the squeeze plate would be pulled up towards the front of the cage and the monkey would be on the bottom of the cage with its back against the squeeze plate. The monkey would then place its hands on handles on either side, and use its legs to push on a plate that contains a force gauge. This design would be able to test the monkey's legs independently, as the handles would contain sensors that need to be activated by the monkey's hands in order to activate the push plate. Like the "Stationary Deadlift" design, the monkey would need to continually need to increase its force on the plate in order to continue to obtain a reward. In this manner, a maximum strength of the monkey could be obtained. This apparatus would be attached to both the front and bottom of the cage while the monkey was in a temporary cage.

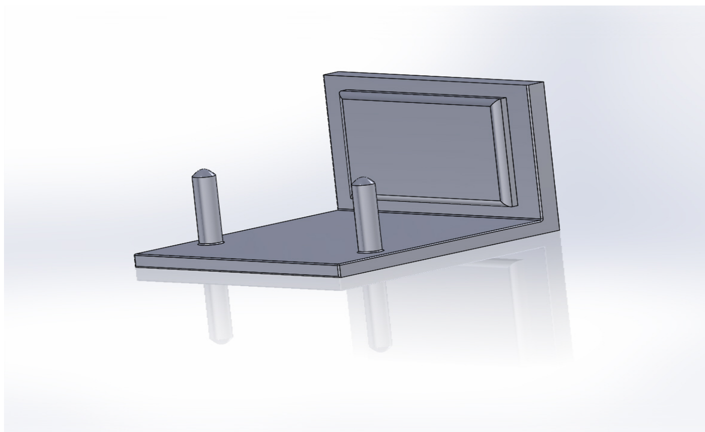

Figure 2: The image above shows the SolidWorks design for the push plate design.

Sliding Cage

The final design considered involved attaching force gauges to the bars connected to the squeeze plate. Like the "Push Plate" design, the squeeze plate would be brought towards the front of the cage. The force gauges would then be attached to the bars, which are now extended past the front of the cage. These gauges would prevent the monkey from pushing the squeeze plate back, while measuring the force placed upon the squeeze plate as the monkey pushes on it. The monkey would push back against the squeeze plate with their legs, as it is natural behavior to do so according to the client. This natural behavior would be reinforced with a reward system similar to the other designs, allowing the apparatus to acquire the maximum strength of the monkey's legs.

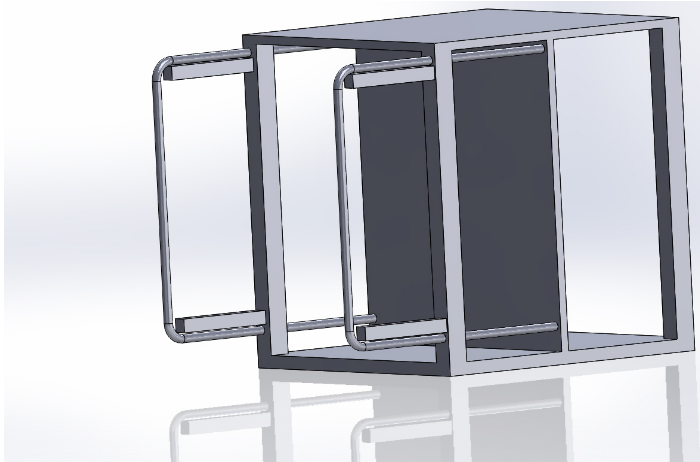

Figure 3: The image above is the SolidWorks design for the sliding cage design.

Design Matrix

The designs were critiqued on seven categories in a design matrix. The design with the best outcome in the areas of safety, durability, difficulty of training, ease of fabrication, ease of use for the researcher, measurement accuracy, and cost was chosen as the final design that we will be moving forward with.

	Push Plate		**Stationary Deadlift**		**Sliding Cage**	
Safety (25)	4	20	4	20	5	25
Durability (20)	5	20	4	16	5	20
Difficulty of Training (Subject) (15)	3	9	4	12	5	15
Ease of Fabrication (15)	3	9	3	9	4	12
Ease of Use (Researcher) (10)	4	8	3	6	5	10
Measurement Accuracy (10)	5	10	3	6	4	8
Cost (5)	5	5	4	4	3	3
Total (100)		81		73		93

Figure 4: The image above is the design matrix for this project. The slide cage

Safety

Safety was the most important aspect of this design because the monkeys will manipulate the device however possible. Because of this key requirement, the design must be completely safe and not cause any harm to the animals. The Stationary Deadlift design was a very safe design because it has little movement and all parts of the device are enclosed inside the shell. The Push Plate design was fairly safe; however, one area that could cause harm to the monkey is the small handles. The Sliding Cage design was very safe because it is not placed in the cage and does not make contact with the monkeys. This is why it received a 5/5 while the other designs received 4/5.

Durability

Durability was very important to this project because the client's research lasts years, and she must be able to test the same muscle force in the same way over her experiments. The Push Plate design was very durable because it uses a small amount of movement in a set pathway to test the force. The Stationary Deadlift design was slightly less durable because the pressure on the sensor would have no resistance to support it, and the sensor would be at risk of being damaged over time with repeated use. The Sliding Cage design was the most durable because the force exerted by the monkeys would be distributed between four sensors placed on the corners of the cage. Due to the distribution of forces in the Push Plate and Sliding Cage designs they both received 5/5 in durability while the Stationary Deadlift only received a 4/5.

Difficulty of Training - Subject

The difficulty of training was defined as the difficulty of teaching the monkeys how to use the design as intended. This category was important to consider because of the length of time it could possibly take to train the monkey to use the device. All designs would incorporate motivation through positive feedback received through food. The difference between the designs involves the complexity of movement that the monkey has to perform. Based on this, the Stationary Deadlift design scored high with a 4/5, as the basic pulling motion should be easy to train. The Push Plate was rated slightly lower at 3/5, as this design incorporated a more complex movement that involved the monkey using both its arms and legs. The Sliding Cage design received the highest score with a 5/5 because the monkeys have already used the squeeze plate feature of their cages before, and they already naturally push back.

Ease of Fabrication

Ease of fabrication was an important consideration, as multiple iterations may have to be fabricated in the future. Additionally, if the fabrication process is simple, it would be easier to make modifications if necessary. The Push Plate and Stationary Deadlift were rated 3/5 due to the need to make enclosed cases for inside the cage as well as adjusting attachment features. The Sliding Cage Design was rated a 4/5 because the monkeys don't make direct contact with the devices, and thus they can have less complex casings and attachment systems.

Ease of Use - Researcher

Ease of use was relatively important because for any of the designs to be feasible, the researcher must be able to install the device and motivate the monkey to use it properly. After installation, the Push Plate is the most easily used device because the researcher can use the back wall of the cage to pull the monkey towards the device and insure they use it. This led to it receiving a score of 4/5. The Stationary Deadlift required the monkey to willingly choose to use it instead of being prompted to use it. This led to this design receiving a 3/5. The Sliding Cage design earned a 5/5 because it utilizes the squeeze plate to insure use, just as the Push Plate does. However, the Sliding Cage design does not require the researcher to take the monkey out of the cage to install the device, which must be done in either of the other designs.

Accuracy of Measurement

Accuracy of Measurement was important because without accurate measurement of muscle force, the device does not perform its purpose. The Push Plate design would perform this the best and receives a 5/5 because it isolates the leg muscles. Also, since the design has handles to occupy the hands, the monkey is less inclined to cheat on the test. The Stationary Deadlift receives the lowest score at 3/5 because the monkey has multiple ways to cheat. They can use their body weight to lean back and create a force or they can use other muscle groups such as theirs arms, back, and core to lift the handle instead of only their legs. The Sliding Cage design received a 4/5 because the monkey can cheat by using their arms. There could also be material bending on the cage wall distributing force away from the sensors.

Cost

Cost was weighted as one of the least important criteria because there was no strict limit on the budget as long as the design was functional and reasonably priced. However, this category was included to guarantee that the designs were cost effective. Since every design incorporated roughly the same materials, the variations in scores were due to the amount of material needed. The Push Plate and Stationary Deadlift were rated relatively high because they only require one force gauge, which is the most expensive aspect of the designs. The Sliding Cage design requires four separate force gauges to compile the full force exerted by the monkeys, so it scored the lowest with only a 3/5.

Proposed Final Design

Based on the design matrix, the Sliding Cage design was the clear choice to move forward with. It scored well in all categories except for cost, which the client agrees is the least important criteria. It achieved the best score in safety, durability, difficulty of training, ease of fabrication, and ease of use for the researcher. The ability to implement the design without the monkey having to be removed from the cage or being in physical contact with the device were two of the design characteristics that made the Sliding Cage design the best choice moving forward.

Future Work

Fabrication

Initial fabrication will begin with background research into finding various force sensors that will work along with the Arduino microprocessor along with finding a plausible circuit that will be integrated into the product. There are several plausible force sensors on the market already, including the FlexiForce Sensors by Tekscan (5) or the various sensors made by the RobotShop (6). The FlexiForce sensors seem to be more durable and smaller; however, these sensors are also about five times more expensive than that of RobotShop.

After designing a circuit, integrating force plates, and combining these both with the Arduino microprocessor, code will be written that analyzes the forces read by the device and provides real-time feedback to the client. This code would ideally save the input while also displaying it graphically to the client.

After the circuit is designed, the product must be connected to a reward system that the client gives us. This will allow for the monkeys to receive awards for their interaction with the device, which should stimulate more tests in the future.

The final step to the fabrication process will be integrating the device onto the exterior of the cage and attaching the force plates to the squeeze plate. The four sensors will be attached in the four corners of the cage and will send the data to the feedback code wirelessly.

Testing

The preliminary testing will begin without the monkeys to ensure the device is working properly. The device will be attached to an empty cage and tested manually by a human user. If the device is working properly, it should allow for the client to see changes in forces in the feedback system. After this testing, the device should be integrated into a cage with a monkey and tested again. This will allow for the device to be tested again, and the client should be able to begin gathering some preliminary data. This secondary test will also allow for the durability of the product while also testing for the response the rhesus monkeys will give to the product. Ideally, the monkeys will not destroy the product in any fashion and will also quickly realize that interaction with the test allows for some reward. After these preliminary tests, necessary improvements will be made in order to reach the clients design requirements.

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Appendix

A. Product Design Statement

Physical Testing Apparatus for Monkeys
Client: Dr. Ricki Colman
Advisor: Dr. Aaron Suminski
Team: Heather Barnwell, Benjamin Horman, David Luzzio, Benjamin Myers, Benjamin Ratliff

Problem Statement:

In studying the effects of diet on the macaque monkey, muscle function and strength give important data to the aging of the test subjects. Currently, only muscle mass can be measured; however, information on the animal's' muscle strength lacks. An apparatus to motivate the monkeys to test their strength, exercise their upper and lower body, and give feedback, isn't available in the primate center on the UW campus. The goal of this project is to develop a method for testing the physical function of the hind and forelimbs of a macaque monkey that will be durable, able to be sanitized, and safe for the animals.

Client Requirements:

1. The device must be able to measure the strength of a rhesus monkey.
2. The device must be sanitizable.
3. The device must not be harmful to the monkey.
4. The device must be durable enough to withstand long-term abuse from a monkey.
5. The device must be resistant to rust.
6. The device must be able to be operated by a monkey after training.
7. The device must be able to give feedback to the client in real time.
8. The device must be able to measure the strength of the monkey's arms and legs separately.
9. The device must be able to be moved by a single person.
10. The device must have a way to reward the monkey with food.

Preliminary Product Design Specifications

Physical and Operational Characteristics:

a. *Performance Requirements:*

The physical testing apparatus for rhesus monkeys should be wear-and-tear resistant with long term durability. The apparatus must be able to test rhesus monkey upper body and lower body strength separately, while providing feedback to the user. The rhesus monkeys are very strong, so the device must be able to withstand large forces from the monkeys.

b. *Safety:*

The device should meet all of the regulations for animal testing established by the Institutional Animal Care and Use Committee (IACUC). The device cannot harm the animals in any way, and we must be careful to design a device that is still safe even if used incorrectly. The device also must be made using a metal that cannot rust, likely stainless steel.

c. *Accuracy and Reliability:*

The device must be able to accurately and reliably relay data to the client on the strength of the animals. Ideally, the device returns leg strength and arm strength as two separate sets of data.

d. *Life in Service:*

The client did not give any specific description into life in service; however, the device will be used several times a day and should be able to last at least a year. The device will be under constant stress while in use, so it must be able to withstand high forces from the animals.

e. *Shelf Life:*

The device should be able to maintain the wear and tear damage while in use with the monkeys. The client stressed the strength of the monkeys and their ability to break devices easily.

f. *Operating Environment:*

The device will primarily be used in the cages that the rhesus monkeys are currently kept in. As a result, the biggest factor of the operating factor are the monkeys themselves. The device also must remain rust free over time.

g. *Ergonomics:*

The testing apparatus must be able to withstand the full strength of the monkeys. It must be easy to use for the monkeys and motivate them to use their full strength.

h. *Size:*

The product should be able to work on different sized cages. It must be detachable so that it can be fully sterilized.It should be portable enough to move from one cage to another. It should have a maximum weight of 40lbs.

i. *Power Source:*

The product can be outlet or battery powered.

j. *Weight:*

The strength testing device should not exceed 40lbs.

k. *Materials:*

All parts that are open to the monkeys should be made from metal or plexiglass so the monkeys can not destroy the equipment or hurt themselves with parts. The apparatus must be rust resistant too.

l. *Aesthetics, Appearance, and Finish:*

This product should have no sharp corners or edges that the monkeys could injure themselves on. It should be smooth enough that the monkeys cannot grab and destroy it. It must be rust resistant.

Production Characteristics:

a. Quantity:

The product may be produced on a larger scale, but a working prototype must be created first.

b. Target Product Cost:

The current product cost is $500.

Miscellaneous:

a. *Standard and Specification:*

The strength testing apparatus must be able to gauge force produced by macaque monkeys during specific forelimb and hindlimb movements and export readings to a data collection interface. It must be attached to and functioned within monkey cages, easily detached and transported, resistant to animal-abuse, dishwasher-safe, and operated without mechanical, electrical, chemical, or biological hazards to the animals. Properties and usage of the device must fall under AWA (Animal Welfare Act) regulations.

b. *Patient-Related Concerns:*

The client's most significant concern is the safety of the device, as aforementioned. In their perspective, the greatest challenge will be creating an apparatus that the monkeys will use properly and consistently. Preferences include minimal requirement of animal and human training to use, reinforcing monkey compliance with an automated reward system, not using physical restraints, and using washable, corrosion and oxidation-resistant materials (such as plexiglass and stainless steel). The client is in favor of operating the device in environments familiar to the monkeys, such as individual cages, to maximize the subjects' comfortability.

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c. *Competition:*

Several monkey-strength testing devices built for individual studies exist. Each mechanism is used with increasing resistance over trial number, and supplies a reward after each successful trial as positive reinforcement. For example, a device utilized by Katarzyna Bozek et al. consists of a sliding shelf attached to a handle on one side, and suspended adjustable weights on the other. Sufficient displacement of the shelf brings food within the subject's reach. Another example is a device utilized by Bury SD et al. that measures grip strength through the squeezing of two halves of an aluminum cylinder against an internal force transducer. If sufficient force is provided, food is dispensed as a reward.

d. Customer:

The client is Dr. Ricki Colman, PhD, an expert on primate aging, caloric restriction, and primate models as well as an associate scientist at the Wisconsin National Primate Research Center.