Design and Implementation of Power Walker Related Experimentation

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Abstract

People often take the ability to walk for granted. What is such a natural activity to most everyone is not always available for children with cerebral palsy to the degree that children without a motor disorder would experience. The longitudinal goal of this project is to provide a motorized walker to children with cerebral palsy to minimize energy expenditure from pushing around a walker. This paper discusses a method of experimentation that will encompass just a portion of this massive endeavor. From pulleys to load cells, this project designs and implements a laboratory set-up that will provide a forward force to a person walking across the floor. This set-up will be used to test if providing a certain percentage of a person's body weight as a forward force will reduce energy expenditure. This design begins as a proof of concept and then grows into a fully formed system that is adjustable to people of various weights during experimentation. The system also works within the constraints of the lab environment by pulling a subject 3.00 ± 0.01 times horizontally than the weight falls vertically. The parachute cord used stretches linearly as weight is added, and the voltage measured with the load cell increases linearly with force from the weight added. If it can be confirmed that a particular proportion of a person's body weight applied as a forward force minimizes energy expenditure, then the walker will be programmed to provide a personalized force to the user. This will reduce their energy expenditure for children with CP in day-to-day life. The results from this experimentation could also be generalized to other mobility devices so that people with motor disorders can walk in the way many others take for granted.

Keywords: walker, cerebral palsy, pulley, parachute cord, energy efficiency

Introduction

Cerebral palsy occurs in about 1 per every 345 children in the US, and it is the most prevalent motor disability that develops in children [1]. Not only can CP make it challenging to walk, but it can also affect precise motor skills, sensory processing, speech functionality, social/emotional/behavioral skills, cognitive functionality, and vision/hearing [2]. While the presentation and severity of these symptoms vary, these developmental challenges can greatly hinder the life of a child in comparison to other children of the same age. There are three types of CP: spastic, dyskinetic, and ataxic [3]. Spastic CP is characterized by stiffness, dyskinetic by uncontrolled movements, and ataxic by balance and depth perception challenges [3]. Unfortunately, there is no cure for this disease, but surgery, therapy, and assistive devices are generally used to help increase a child's quality of life [3]. Walking, although a simple action many people take for granted, is greatly beneficial for physical and mental health. The impact from when the foot hits the ground sends blood through the arteries and to the brain [4]. More blood in the brain means more oxygen, which in general causes an improvement of memory, cognitive function, and durability [4]. Not only do these children need something to help them participate in life's activities like other children their age and experience autonomy, but also, they need to walk for the health benefits of having more blood sent to their brains.

For 7.8% of children with CP, the ability to walk is accompanied by the need for a hand-held device, such as a cane, crutches, a wheelchair, or a walker [1]. Anterior walkers are pushed in front of the user, and posterior walkers are pulled from behind [5], and both are commonly used. Pushing a walker causes the user to expend more energy than walking normally, so children are not able to keep up with their peers in terms of mobility [6]. To help these children live as normal a life as possible, Barron Associates is developing an intelligent, motorized walker that will provide a forward force to children as they move. However, this company needs to confirm that providing this force will in fact reduce energy expenditure. A study titled "Changes in Kinematics, Metabolic Cost, and External Work During Walking With a Forward Assistive Force" conducted by Christopher Zirker, Bradford Bennett, and Mark Abel in 2012 found that providing a force that is 8%

of the subject's body weight results in the least amount of energy expenditure [7]. However, this experimentation used a treadmill and needs to be recreated on flat ground. The aim of this independently conducted project is to find the percentage of body weight a forward force must provide so that a subject walking on flat ground exerts the least possible amount of energy. This data will be used in the walker to help children with cerebral palsy, but the design and construction of the walker itself is outside the scope of this project.

There are two primary aims for this project. The first is to set up a system using rope and pulleys that provides a manipulable forward force while working within the constraints of the lab environment. The second is to use a load cell and belt to attach the rope system to a test subject and measure the force being applied to the subject. It is critical through this entire process that the system is safe, functional, and adjustable.

Results

Mechanics

The final system design is shown in Figure S1. The overall system can be split into three sections: around the hanger, around the lower hanging pulley, and around the load cell. The section around the hanger is shown in Figure 1. This was set up by hanging two pulleys from a hanger bolted into the wall. Since the hole in the hanger was relatively small, one carabiner was looped through the hanger, and two carabiners were looped through the first one. One pulley was hung on each carabiner. The parachute cord was then threaded through each pulley.

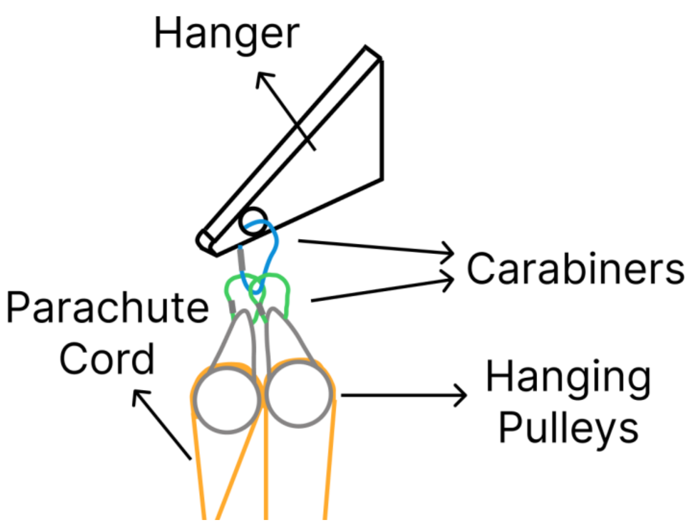

Fig. 1. Labelled pulley system segment around the hanger.

The section around the lower hanging pulley is shown in Figure 2. This figure demonstrates how the three segments of parachute cord were supporting the weights hanging below. To attach the cord to the center of the pulley, two u-bolt plates were situated on both sides of the pulley's clevis pin. The cord was then tied between the holes on the other end of the plates. The system originally just had the weights tied to the pulley with a rope, but this made it difficult to change the weight. It also greatly reduced the distance that the pulley could fall. The design was adjusted to lie the weights horizontally. One end of a turnbuckle was attached to a carabiner that could be easily hooked onto the pulley. The hook on the other end was replaced with a metal plate held in place with a washer and bolt. The turnbuckle could be easily removed from the carabiner, making it significantly easier to adjust the weights being hung. It did introduce 0.45 lbs of weight, but it was constant and accounted for.

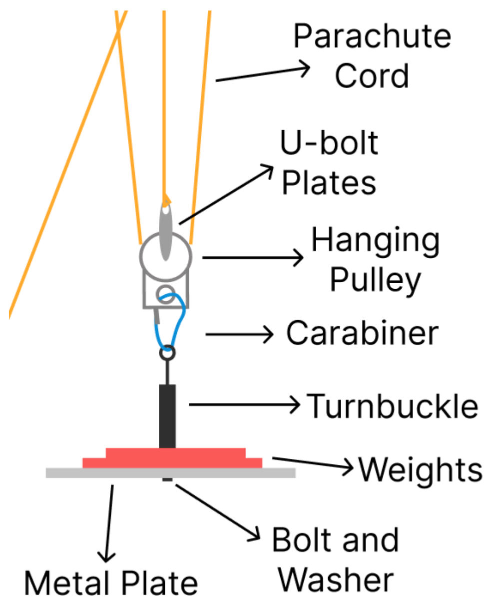

Fig. 2. Labelled pulley system segment around the lower hanging pulley.

The section around the load cell is shown in Figure 3. A pulley bolted onto the wall (not shown) redirects the parachute cord from traveling vertically to horizontally which allows the system to pull a test subject across the floor. The end of the cord is tied to one side of the load cell. Since the attachment locations of the load cell are so small, an appropriately sized turnbuckle was attached. Then, an anchor shackle was attached to the turnbuckle to produce an opening large enough for the belt to be threaded through. The belt could then be tied around the waist of the test subject.

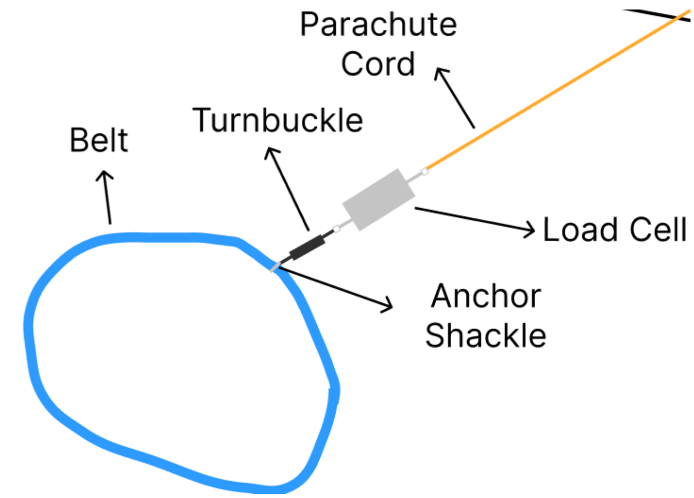

Fig. 3. Labelled pulley system segment around the load cell.

Testing

Length Test

The length test was perhaps the most important test for the set-up. A design constraint was that the system would work within the confines of the lab, meaning that the subject needed to move horizontally about 2.5 times farther than the weight fell. Therefore, it was critical to test the proportion of subject movement to the weight's falling distance. This was done by measuring both distances when the weights were released from the highest possible point and allowed to fall as far as possible. The horizontal distance pulled was fixed at 42 ft, and the distance the weight dropped was measured as weight was added. After seven trials at varying weights, the proportion of the horizontal distance pulled to vertical distance fallen was calculated to be 3.00 ± 0.01. Compared to the theoretical value of 3, the average error was 0.04 ± 0.03.

Force Test

Figure 4 shows that there is a linear relationship between the force from the weights hung and the voltage measured by the load cell. This means that, the force from the weights hung in the system will be linearly related to force on the subject and easily manipulated.

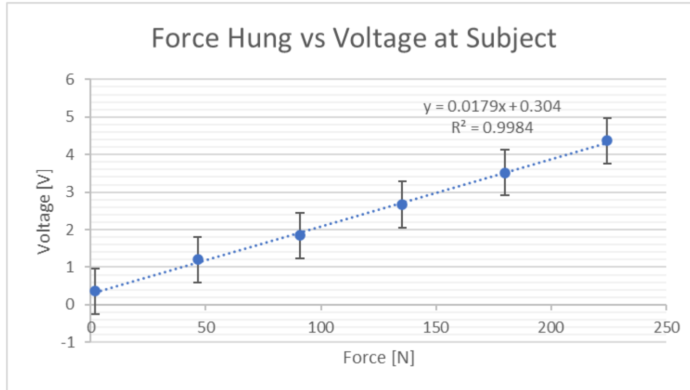

Fig. 4. Graphical analysis of relationship between force from the weights hung and voltage calculated by the load cell and read from a voltmeter. This voltage reading is directly proportional to force in Newtons; however, the load cell was incorrectly calibrated, so these force values cannot be calculated.

Stretch Test

Two tests were conducted on the cord itself to determine the cord's properties. The first test was a stretch test to determine how the cord would react under a load. There is no foreseeable problem with the cord stretching, but it is useful to understand how it works in case the experiment was redone with another type of rope. Stretch could play a factor in the difference of results. This test was conducted by fixing one end of a rope and allowing it to hang vertically. The loose end was tied to the carabiner which held the turnbuckle and plate. Weights were added in increments of 10 lbs, and the distance between the plate and ground was measured. It was found that there was a linear relationship between this distance and weight hung (as shown in Figure 5). Since this distance is proportional to the change in length due to stretch, the linear relationship applies to both.

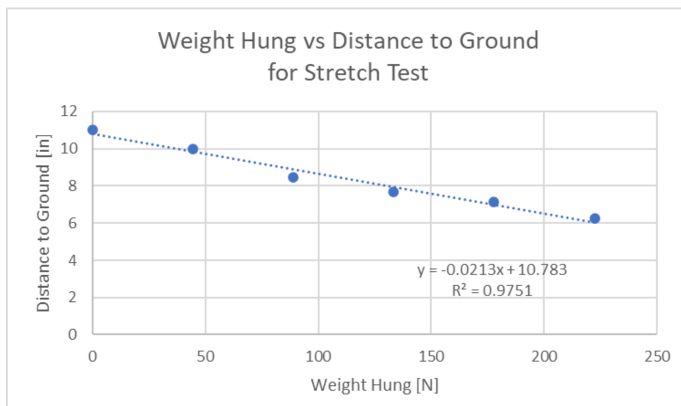

Fig. 5. Graphical analysis of relationship between the weight being hung from the parachute cord and the distance to the ground.

Discussion

To understand why the system is arranged as it is, it must first be understood why three hanging pulleys were necessary instead of just one. Within the constraints of the lab, the weight could only fall 16.79 ft. However, a walking distance of at least 40 ft was required to receive enough data for the analysis. The system with two upper and one lower hanging pulley and a pulley bolted into the wall. One of the hanging pulleys and the pulley bolted into the wall serve only to redirect the force from pointing upward to horizontally attaching to the subject. The other two pulleys provide the force distribution shown in the free body diagram in Figure 6.

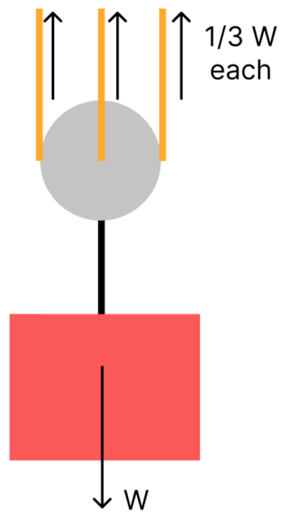

Fig. 6. Free body diagram of the system segment around the lower hanging pulley. This demonstrates how the forces are divided based on the way the pulley is arranged.

The person on the end of the rope would experience a pulling force equal to a third of the weight. This means that the weight, when allowed to fall for the same amount of time, will only fall a third of the distance than if it was attached to a single rope and allowed to fall. This is what allows the rope to pull the subject three times as far.

This design was chosen because it was the simplest design to assemble and required the fewest number of pulleys. A few of the other designs would quadruple the distance. They were considered to make sure that the horizontal distance was long enough, but they were ultimately discarded because they required significantly more cord and pulleys. This means it would cost much more and need more work assembling the system for additional distance that was not necessary.

The length test proved that the system does in fact pull horizontally three times the distance the weight falls vertically. There was very little error, but it was likely due to friction in the system. However, parachute cord was chosen because of both its strength and minimal friction it would introduce. Since the entire functionality of the system depends on the principle of pulling farther than the weight falls, this conclusion is critical to abiding by the lab constraints.

The force test was conducted simply to prove that the load cell could be properly used in the system. It also served to explore whether the force from the weights and force on the subject were linearly related for ease of experimentation. Unfortunately, the load cell used in data collection was incorrectly calibrated, so it did not give accurate voltage readings. Therefore, it was not possible to calculate correct force values. However, the set-up was put in place to solve the length problem, and it does not matter how the system affects force as long as the effect is easily understood and manipulable. Also, the data showed a linear relationship between force hung and voltage meaning that, once the load cell is correctly calibrated and the conversion factor is known, there will be a linear relationship between the hung force and force on the subject. This reveals that the load cell was properly used, and the force on the subject can be easily changed and measured to the needed value.

Limitations

There were several limitations during this process that must be discussed. First, the incorrect calibration in the load cell provided the greatest limitation. The source of incorrect data was not discovered until it was too late to calibrate the device and redo the testing. Another hardware related limitation related to one of the hanging pulleys. These were positioned before it was fully understood how the system would be assembled, and one had a max load of only 55 lbs. Although this limit was never breached, the pulley did break. An easy solution, however, is just hanging a pulley similar to the other ones used with a higher max load.

Had time allowed for the experiment to have been conducted while measuring energy expenditure, a VO2 analyzer mask would have been utilized. This mask would need to be thoroughly sterilized and multiple precautions would need to be taken to ensure that subjects are not at risk of contracting COVID. Also, the experimentation will be conducted primarily on college-aged students because that is an easily accessible population. While this is acceptable for the first stage of testing, it is critical to find test subjects with cerebral palsy since that is the population for whom the walker is being designed.

Future work

The next step in this project would be to obtain Institutional Review Board (IRB) approval to begin testing. The experiment would begin using the VO2 analyzer mask to measure how oxygen consumption changes depending on the percentage of a subject's body weight applied as a forward force. This would first be done with college-aged students, but the next step would be to conduct this experiment with children who have CP and an elderly population. There would be minimal adjustments needed to modify the system since it was made to be adjustable. Most likely, the only change would be lowering the pulley bolted to the wall to accommodate a shorter person. It is not critical, but it would be useful to add some sort of quick stopping feature to the system. As it is currently designed, there is no way to stop the weight from falling other than holding the rope in place. If a population using the system has a greater fall risk than college-aged students, it would decrease risk to have a way to lock the weight in place in the event of a fall. One way to do this would be to use a motor instead of weights and pulleys. A motor that can be controlled from a computer would be easy to stop if necessary. Additionally, testing on an elderly population would contribute to expanding the walker for geriatric use.

Materials and Methods

Multiple pieces of hardware were used in the construction of this system: parachute cord, a load cell, exercise weights, pulleys, carabiners, u-bolt plates, turnbuckles, a metal plate, an anchor shackle, and a belt.

The parachute cord used was 100 ft of Blue Hawk Parachord. This was chosen because it is lightweight, has low friction, is inexpensive, and has a maximum load of 110 lbs. The load cell has a 900 N max load, which translates to 202.3 lbs. The force applied to the load cell should, theoretically, never be greater than 202.3 lbs. Additionally, this load cell produces more accurate voltage measurements than larger ones with a higher max load. Therefore, this was the ideal choice for load cell. The weights used were exercise weights, so they were round with a round hole in the middle. Each weight was 10 lbs. One hanging pulley is zinc plated with a max load of 420 lbs and the other nickel plates with a max load of 55 lbs. The lower hanging pulley was also zinc plated with a max load of 420 lbs. All pulleys are National Hardware brand.

Four carabiners total were used, and since they were made for rock climbing, they were capable of supporting much more force than would ever be applied onto the system. The two u-bolt plates were removed from the u-bolts and used so that the rope could tie to the center of mass of the hanging pulley. Two turnbuckles were used but served different purposes. The first was used for its interchangeable ends. A loop was inserted into one side and a bolt into the other. The side with the bolt held the metal plate in place so that the weights could lie on top. The side with the loop made it easy to attach or detach from the carabiner so that the weight could be changed but the system was still closed and secure. This turnbuckle has a max load of 215 lbs. The other turnbuckle was used because the connection to the load cell was too small for the belt to fit through. It has a max load of 45 lbs. Although more weight will be used in the system, this turnbuckle just needs to support the force on the subject, which will be significantly less since it is only 8% or a person's body weight. The metal plate is a cut piece of metal with a hole drilled into the middle and the edges smoothed. The anchor shackle was used because the carabiner attached to the load cell was still not big enough to attach to the belt. However, the anchor shackle was too small to attach to the load cell, so both were used to attach the load cell to the belt.

End Matter

Acknowledgments

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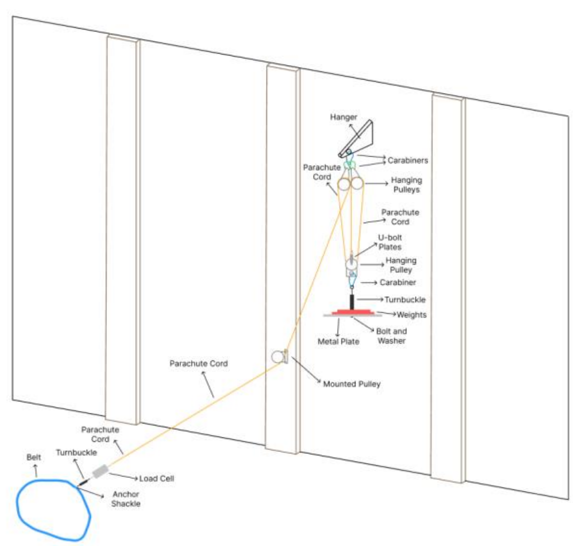
Supplements



Supplementary Fig. 1. Fully labelled diagram of system

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