Enabling Overground Walking During Motion Capture Pulling Force Trial

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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

For the technical project, a bidirectional assisted walking system was developed. Cerebral palsy is the most common cause of physical disability in children affecting 2 to 3/1000 children worldwide. About 31% of children with CP in the US use special equipment of some kind. When it comes to mobility, many individuals with CP rely on walkers or wheelchairs. As part of his PhD project, Evan Dooley is designing a power walker to allow children with CP to spend a longer amount of time per day on their feet, by decreasing the amount of effort it takes for people with CP to get around. In order to do this, there is a need to know how much pulling force the walker will need to apply based on the person's body weight. Typically, these types of measurements are done via treadmill walking, however treadmill walking elicits different gait patterns than normal, or overground walking. Such as differences in stride length and phase durations. Our goal was to create an overground walking system that will allow for continuous data collection. In order to do this a bidirectional system was constructed that has a pulling force on each end applied by a weighted pulley system and a belt that allows for turning 180 degrees. The system is also compatible with a VO2 measurement system so the metabolic cost of different body weight percentages of applied forces could be examined.

Key words: overground walking, gait analysis, metabolic cost

Introduction

Many people with Cerebral Palsy (CP) and other physical disabilities use walkers to increase their mobility options. Motorized walkers reduce the amount of physical exertion necessary to ambulate, making it easier for individuals to stay on their feet for longer, which can slow disease progression in addition to enabling greater independence for the user. To design the most effective motorized walker, it is necessary to understand what magnitude of pulling force, when applied to the user, is the most assistive.

Previously Used Methods

There have been several studies previously conducted that also utilize a pulling force on an individual through different methods. One study focusing on identifying the fall potential of an individual with Parkinson's Disease (PD) utilized a system of pulleys and a harness to administer a reproducible mechanical pull force on an individual [1]. This study applied the pulling force to the individual's while they were standing still. The application of the pulling force follows the general idea of what is necessary for the creation of the powered walker. However, to properly identify the ideal percentage of an individual's body weight to apply as a pulling force, gait analysis is required. That would mean that this methodology is not applicable in relation to the development of the walker.

While the study relating to PD used a methodology that did not involve gait analysis, there are other studies that incorporate movement and an applied pulling force into their methodology. One study that was designed for research involving those recovering from stroke used a treadmill for the individual to walk on while applying a pulling force [2]. The pulling force was applied to the paretic side of the pelvis in order to encourage the shifting of the pelvis towards that side during the stance phase of gait. While this study does apply a pulling force to an individual as they are moving, it does not necessarily meet the criteria of incorporating a forward pulling force designed to be incorporated into gait analysis. In order to provide the necessary data regarding metabolic cost for the development of the walker, it is important to develop a system and methodology that will allow for a forward pulling force to be applied during gait analysis.

Treadmill versus Overground Walking

Continuous data collection for gait analysis data typically utilizes a treadmill. There are a handful of benefits that some researchers have identified as helpful in relation to the use of treadmills for gait analysis [3]. One example of a type of benefit would be controlling the speed of the individual while they are walking and between sessions, which for rehabilitation research, can be very beneficial. Another beneficial aspect of using a treadmill for gait analysis is that they typically take up less space and can be used in a variety of research or clinical settings. However, even with these benefits noted, there are some limitations and drawbacks to using a treadmill for gait analysis that make it less than ideal for the development of the power walker.

Treadmills, while useful in some cases, also cause differences in gait patterns [3]. Gait patterns and spatiotemporal parameters that are seen when an individual walks on a treadmill as compared to overground are not as natural as treadmills tend to elicit different patterns [4]. In the study by Hollman et al., it was found that there was a statistically significant difference between the stride time and cadence of an individual walking on a treadmill compared to an individual walking overground with an effect size of more than 1.5. Another study found that stride length had decreased significantly by 7% [5]. The increase in the step time and cadence of walking when on a treadmill result in alterations in the walking cycle with one study reporting that stance phase decreased by 7% and swing phase increased by 5% during treadmill walking [6]. As a result of the changes in the gait pattern and the prolonged swing phase, the study by Stolze et al. reported that there was a 27% decrease in double limb support leading to notable changes in balance related gait patterns.

These differences in gait patterns are not the only aspect of data collection for gait analysis that are impacted by the use of a treadmill. There are reported instances of differences in kinetic data between overground and treadmill walking. An example of this would be that joint moments in the sagittal plane were found to be statistically different when comparing treadmill and overground walking [7]. The study by Lee and Hidler found that overground walking produces larger knee extensor moments throughout the gait cycle compared to treadmill walking. They also found that treadmill walking caused hip extensor moments during early stance and late swing to be significantly greater than those during overground walking and that the hip flexion moment was significantly more negative also during treadmill walking.

Along with changes to gait patterns and kinetic data, the use of a treadmill for gait analysis also has the potential to add noise to the system. A treadmill requires a belt and motor to function, however these would sit next to or on top of the force plates that would be required for gait analysis to be completed [8]. The belt and motor of the treadmill would impact force plate data in a number of ways, from adding horizontal friction onto the vertical force plate sensors, to generating incorrect force readings from the belt creating an extra downward force onto the plate or upward vertical force from the belt tension, or the motor causing the force plates to vibrate. As a result, treadmill force readings could be incorrect or noisy, potentially misrepresenting collected data. It is for that reason and the differences between overground walking and treadmill walking that exist in respects to gait patterns and kinetics data that an overground system must be developed. An overground system that allows for an applied pulling force would potentially eliminate the noted issues that exist in the current treadmill pulling force systems. To ensure that the powered walker is developed with the most accurate data an overground system must be used for preliminary data collection.

With the noted deficiencies of previously used applied pulling force studies in relation to the development of a powered walker and the differences with gait patters, kinetic data, and added noise that treadmills generate, the goal of this project is to develop an overground system for enabling applied pulling force during motion capture gait analysis. The system must be able to provide data relevant to determining the ideal percentage of body weight to be used for an assistive pulling force during overground walking. Utilizing the space of the Motion Analysis and Motor Performance (MAMP) Lab at the University of Virginia (UVA), the pulling force will need to be able to be applied consistently for the entirety of the 50ft walkway available. As the pulling force has to be continuously applied, the system must also allow for continuous data collection, meaning that the individual must be able to walk the length of the 50ft walkway and turn around 180° and walk back, all while maintaining the application of the pulling force. As part of the overarching goal of this project is for the overground pulling force system to be used in conjunction with other gait analysis equipment pieces, the developed system must be compatible with all other aspects of gait analysis data collection. Validation of the system during gait analysis and metabolic cost trials is necessary to ensure proper functionality and application of the overall system. Prior to the validation process, it was hypothesized that the system would be compatible with current motion capture technology.

Approach

To create a system for generating a pulling force in one direction, a three pulley system was utilized, as displayed in Figure 1. One pulley leads out to the individual walking and then back up towards another pulley. Weights are attached to one of the pulleys to generate a downward force in the system that would allow for the pulling force to be generated through the use of the other two pulleys. The pulley that leads out to the individual walking allows for the application of the force generated by the weights to be applied horizontally to the individual walking. Through the use of all three pulleys, the weights can generate a downward force by being pulled up as the individual walks away from that particular wall and dropping down as the individual walks towards that wall, which then creates the horizontal pulling force. This three

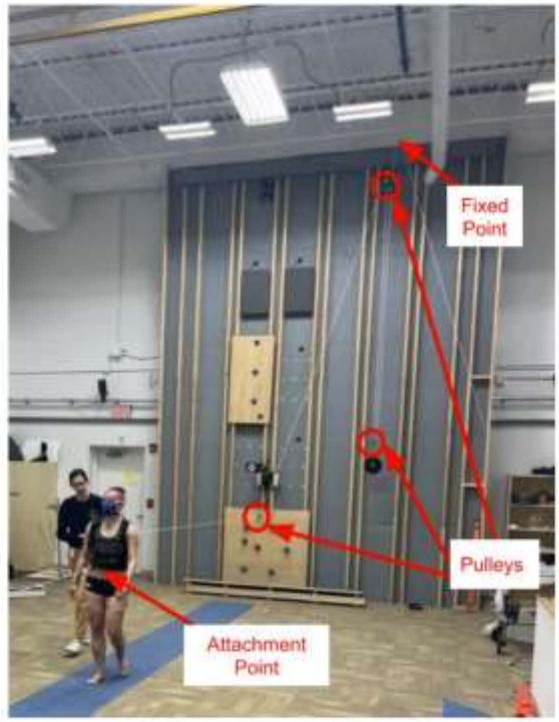

Figure 1. Three Pulley System for Applying Force. This figure displays what one side of the bidirectional pulley system looks like. Each side is a mirror of the other, with one pulley attached to the weights and another coming out towards the attachment point on the individual walking.

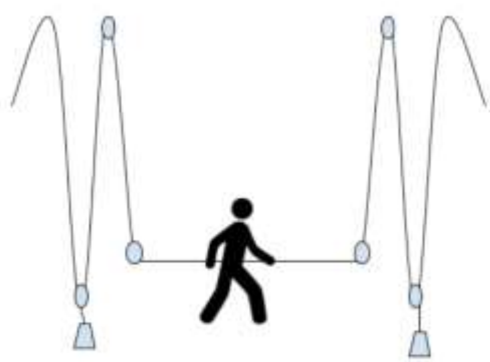

Figure 2. General Sketch of Pulley System
This 2 dimensional sketch displays the general set up for the pulley system. The pulleys are located on the two walls of the MAMP lab, with the bottom pulley having the weights attached to them. The individual walking in the middle is between the two walls with the belt attached to them to allow them to turn around.

pulley system is what allows for the pulling force to be generated and applied to the individual as they walk. As this is a bidirectional system, the three pulley system is mirrored on each end of the 50ft walkway in the MAMP lab, as displayed in Figure 2, to allow for a pulling force to be applied in whichever direction the individual is walking towards.

When using pulleys, it is important to understand how they distribute force and what implications that has for the development of the system to apply a force during overground walking, motion capture trials. Through the weights on one side falling as the individual walks towards that side, tension is applied to the rope through the pulley, following the force body diagram depicted in Figure 3. As about half of the weight added to the pulley system is applied as tension in the direction of the individual walking, the other half of that force is directed towards the fixed point at the top of the ceiling. As a result, this means the individual only has half of the weight added applied as a pulling force. This has several implications for the system. One of these implications is that the angle at which the pulley with the weights falls must be as close to vertical as possible as to ensure that the tension in the rope directed towards the individual is as close to mg/2, or the true amount of force, as possible. The other implication is that when body weight percentages are calculated, double the amount calculated must be added to the pulley system in order to apply the calculated weight as a pulling force. This again is due to the fact that the distribution of tension in a pulley on either side is mg/2, meaning that each side of the pulley receives half of the applied force. So, if a weight is calculated to be 4% of an individual's body weight, 8% must be added to the pulley system for the 4% to be applied to the individual.

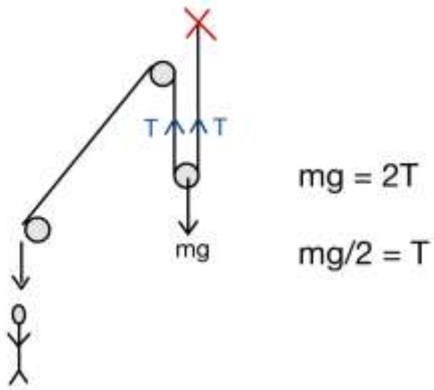

Figure 3. Pulley with Attached Weight Force Body Diagram: This figure displays the force body diagram for the pulley in the system that has the weight attached to it. The diagram illustrates the force distribution through the pulley and how half of the attached weight is applied to either side of the pulley, meaning only half of the attached weight is applied to the individual.

To ensure the ability for motion capture and gait analysis data to be continuously collected, the individual walking must be able to walk the length of the 50ft walkway in the MAMP lab and then turn around and walk back, all while a forward pulling force is applied. To allow for this to happen, an adjustable rotating exercise belt is employed. The belt that was decided on was the *Yoonsoe Detachable 24 Sections Smart Weighted Exercise Hoop Adults Non-Fall Fitness Hoop for Weight Loss.* This belt was chosen for several reasons. The belt is adjustable as it has detachable pieces, as seen in Figure 4, allowing for it to be modified from 31.49 inch to 47.24 inch [9]. The belt also allows for rotation with bearings and a flexible axel that run on a track around the circumference of the belt.

In order to use the belt to apply a bidirectional pulling force, two separate flexible axles are needed. One axle attaches to the rope that originates from the wall that the individual is walking towards, providing the applied pulling force. The other attaches to the rope leading to the wall behind the individual walking. The ropes attach to the axles with carabiners at the attachment point displayed in Figure 4. These axels allow for the individual to turn around without detaching from any of the ropes as they rotate as the individual turns. The use of the rotating exercise belt is what truly ensures continuous data collection, which is a key component of gait analysis, motion capture, and metabolic cost data

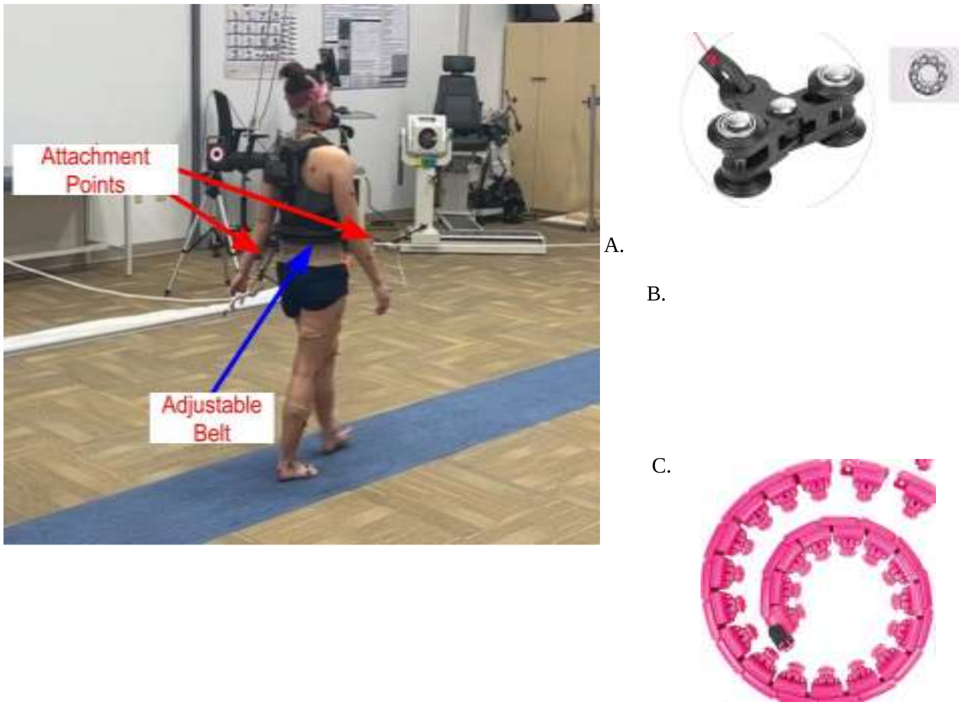

Figure 4. Belt Features and Attachment Points. The images show the key components of the rotating exercise belt that allow for its use to ensure continuous data collection. (4A) Depicts the belt in use during data collection and displays how the rope attaches to the axles on the belt. (4B) Shows the flexible axles and bearings allowing for rotation around the circumference. (4C) The belt has detachable pieces allowing the for belt to be altered for the individual using it.

Results

Preliminary data collection was conducted to evaluate the system's overall efficacy, usability, and compatibility with the motion capture equipment as well as the appropriateness of the potential pulling force magnitudes. This data collection was run on one subject with four different pulling force magnitudes. Future studies will be necessary to gather statistically significant results. Figure 6 illustrates one example of data collected from a trial with 8% body weight. Metabolic cost for the exercise period (in which the subject was pulled while walking) was averaged and divided by metabolic cost for the rest period to find the normalized metabolic cost values depicted in Figure 7 for each trial type.

At the conclusion of the preliminary data collection, the system was deemed helpful by the MAMP Lab researchers, meaning it effectively works alongside their current equipment (pictured in Fig. 5) and methods. The researchers therefore expressed an intention to continue to use the pulley system in future studies.

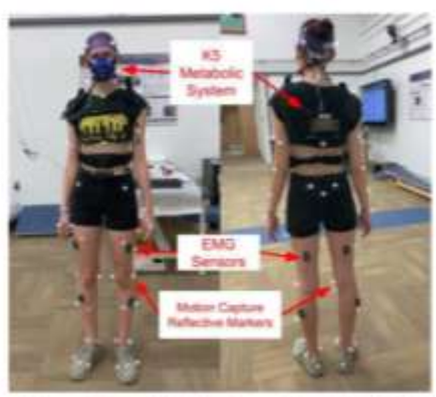

Figure 5. Standard Equipment for MAMP Lab Motion Capture Studies. Images showing motion capture equipment worn by each subject during data collection. Design of the pulley system and accompanying belt needed to be compatible with existing equipment.

Figure 6. Individual Trial Data. Data from one trial at 8% body weight. VO2 output average from the last 1.5 minutes of the exercise period is divided by VO2 output average from the entirety of the rest period to find normalized metabolic cost for each trial.

Discussion

The preliminary data collection was conducted for two reasons. First, to establish a starting range of weights as a percentage of subject body mass that should be used in future trials when looking to identify a specific "goldilocks" percentage for the ideal pulling force. Second, to evaluate the pulley system's ability to be used alongside standard motion capture equipment during an actual walking trial.

The preliminary data indicate that the chosen range of body weight percentages used as pulling forces in the preliminary trials was too low. Had the correct range been identified, the data would show a decrease in metabolic cost as weight was increased, followed by an increase in metabolic cost after the weight percentage exceeded the ideal zone. Instead, the data indicate no significant improvement in terms of metabolic efficiency as weight is increased. This means that future studies should not use minimum pulling force percentages lower than 8%, since all forces below that seem to have a similar impact, as seen in Fig. 7.

In terms of compatibility with current field standards, the preliminary data collection was also successful. The pulley system coexisted alongside the MAMP Lab's motion capture equipment (namely the K5 Metabolic System, EMG sensors, motion capture markers and corresponding Vicon cameras, and in-ground force plates) seamlessly. The researchers' statements of intent to continue using the system indicate an effective implementation.

Future Directions and Limitation

The current mirrored pulley system to apply a bidirectional pulling force has a few key limitations. One of these limitations is that in order to have the weights move up towards the ceiling as the individual walks away from that wall the rope would be exerting a backwards pulling force on the individual. To prevent that from occurring so that the only applied force was a forward pulling force, another individual needed to walk behind the individual that data was being collected on and pull the back rope so that the tension in the rope did not reach the individual walking. This prevents a backward force from being applied, but requires an extra person to be present during data collection. There are a few drawbacks to this, one would be the be

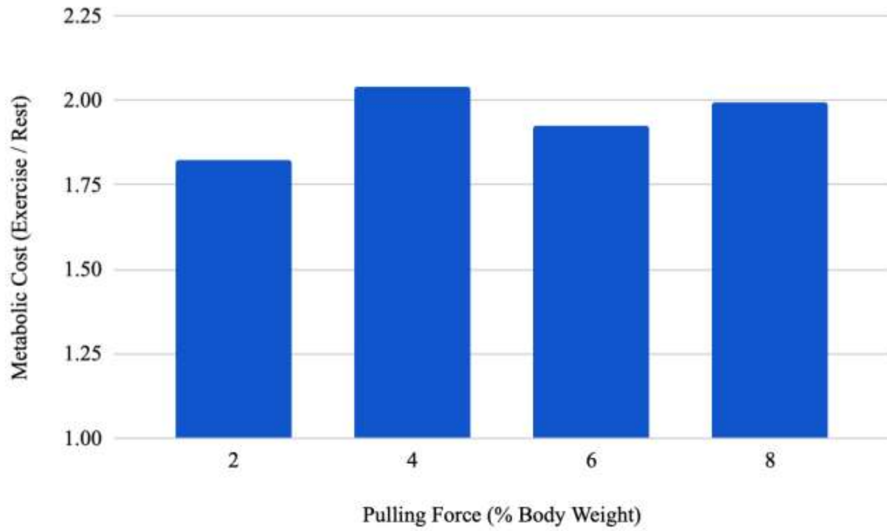

Figure 7. Processed Data From All Trials. Results from preliminary data collection. One subject with one trial per pulling force option means that no statistically significant conclusions can be drawn from the current data.

individual preventing the back rope from applying a force must be able to bear the weight applied to the rope, they also must keep up with the individual walking, and could potentially be obscuring the view of some of the motion capture cameras.

Another limitation of the current system is that weights can only be added in half pound increments. This can be a problem when trying to provide precise amounts of weight that directly correspond to a specific percentage of an individual's body weight. By adding half pounds at a time there is the potential that the amount of weight that would match up to the body weight percentage amount would not be possible to add to the system. The availability of weights to add are therefore a limiting factor of the system as it cannot possibly have an exactly precise way to apply the correct pulling force for testing.

The potential next interaction for a system to apply a continuous forward pulling force to an individual during motion capture trials would be to utilize a motor based system. A motor based system would allow for a specific amount of tension to be applied to the rope [10]. The specific amount of force applied as tension to the rope can be translated into a torque input that would then match the amount of force that should applied as a percentage of an individual's body weight. This allows for a more precise way to apply the forward pulling force to the individual rather than the current system of adding weights in half pound increments.

Also, by implementing a motor based system to apply the pulling force, the ability to automate the system is created. The current pulley system requires someone to walk behind the individual walking and release tension in the back rope to prevent a backwards force from being applied. A motor based system would enable the rope to unfurl from the spool as the individual walks away from it without applying a backwards force. This would eliminate the potential of the individual releasing tension from obstructing the view of motion capture cameras and any of the other previously listed drawbacks that existed from having someone walk behind the individual walking for motion capture data collection.

Conclusion

The developed pulley system allows for the accurate quantification of ideal pulling forces for over ground walking while being compatible with existing motion capture equipment. Future work to replace the pulleys with a motorized implementation could result in a design that is simpler and more efficient to use. As it stands, the system will enhance the design of a motorized walker for people with CP and similar disabilities. Such a device will increase quality of life for its users by providing greater opportunities for independence and make it easier for them to stay on their feet for longer, thereby slowing disease progression.

End Matter

All authors conducted initial research and literature review. All authors designed the pulley system. All authors set up and constructed the pulley system. All authors wrote the paper. All authors analyzed the data.

The authors declare no conflict of interest.

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