The Benefits of Cycling: Adaptive Cycling and Dandy-Walker Syndrome

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Abstract

Cycling can immensely benefit people with special needs, such as disability, disorder or disease. Through various types of cycles including tricycles, tandem cycles, and handcycles; adaptive cycling can provide transportation, exercise, and therapy for the special needs population. Bicycle use positively affects transportation through its cost effective nature as well as reduced levels of pollutants emitted. Cycling also poses numerous physical health benefits gained through both exercise and competition. The U.S Handcycling organization, as well as the Paralyzed Veterans of America (PVA) provide opportunities for recreational and elite competition for the physically impaired adaptive cyclists. Adaptive cycling has been shown to be therapeutic and have many medical benefits as well. Specifically, the condition of those with Cerebral Palsy (CP), Parkinson's disease, paralysis and stroke, and Dandy-Walker Syndrome can improve as a result of cycling. There are numerous benefits that individuals with Dandy-Walker Syndrome can receive through cycling when specific modifications are made to the bicycle.

A custom tricycle was designed in order to provide benefits of cycling for a subject with Dandy-Walker Syndrome. Dandy-Walker Syndrome is a congenital brain malformation affecting the cerebellum. As a result, the balance, muscle coordination, and reflexes of the individual are impaired. Specific symptoms such as low muscle tone (hypotonia), and poor coordination and balance (ataxia) may affect the individual's ability to ride a bicycle. The four main areas where the patient may have weakness or impaired skills are balance, functional mobility/gait, strength, and coordination. In order to assess the required adaptations for a bicycle, the subject was tested using research-based benchmark tests. The balance tests used were the Romberg and Tandem Romberg, the Single Leg Stance test, and the Functional Reach test. Functional mobility and gait were assessed using both the Timed Up and Go test as well as the Timed Up and Down Stairs test. A Jamar dynamometer and a hand-held dynamometer were used to measure the strength of the primary muscles involved in the cycling pedal motion. The subject's muscular coordination was tested using the finger-to-nose test. The benchmark test results were evaluated to translate the physical impairments of the subject with Dandy-Walker Syndrome into bicycle adaptations necessary to improve bicycle design. An upright tadpole configuration with the ability to tilt was chosen to provide maximum benefits for improving balance and coordination. The tilting mechanism can be locked out if needed. Clip-less pedal shoes, a wider bicycle seat, a chain

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guard, and both higher and wider handlebars were recommended to best accommodate for the individual's physical impairments and weaknesses.

Introduction

Cycling is an excellent form of exercise that has numerous benefits for people with special needs and healthy individuals alike. Tricycles, handcycles, tandem cycling, and the standard upright cycle can all provide physical benefits in the form of exercise or competition and medical benefits through therapy for many diseases, disabilities, and disorders[1]. In addition, cycling can provide a healthy, cost-efficient mode of transportation for individuals.

There are various types of bicycles and adaptive cycles that can be utilized by people of differing physical impairments and special needs. First, tricycles or "trikes" are cycles with three wheels instead of the conventional two. There are two main types of tricycles: the tadpole trike, and the delta trike. The tadpole trike has two front wheels and one wheel located in the rear of the cycle. It is considered the more light-weight, compact, and aerodynamic of the two tricycles. Conversely, the delta trike has two wheels at the rear of the bike, with a single wheel in front[2]. Tricycles can be used by individuals who have impairments that affect their ability to balance a bicycle since the addition of a third wheel makes the tricycle stable.

Another type of cycle utilized in adaptive cycling is the handcycle. Handcycles are a type of human powered vehicle that closely resemble a bicycle in purpose and movement, however, are powered by the arms instead of the legs. This change results in a very different design. Handcycles can provide the benefits of exercise and competition for the disabled, specifically those with lower limb impairments[3]. There are many different designs and adaptions of handcycles to fit the needs of each individual rider. The two types of handcycle seating configurations are trunk powered and recumbent. The recumbent handcycle rider sits in a seat with a reclined back, positioning the rider underneath the cranks[4]. The rider utilizes mainly the arm, shoulder and chest muscles to power the cycle. This has been found to be the best choice for paraplegics (T10 level and above) and quadriplegics[5]. Alternately, the trunk positioned riders are able to use more core strength and also put some body weight over the cranks. These riders are employing more muscles groups and proportionately more body weight, therefore exerting more energy and becoming fatigued more quickly. With the trunk powered arrangement, riders are able to put the weight of their trunk behind each pedaling stroke, allowing them to go faster for longer. The limitation to "trunk powered" handcycles is that the athlete must have use of most or all of their abdominal muscles in order to control the cycle[4].

Another bicycle modification that allows visually impaired individuals to cycle for both recreational exercise and competition is the tandem bicycle. Tandem bicycles are designed to be ridden by more than one rider. However, the term "tandem" refers to the seating arrangement, not the number of riders. In a standard tandem bicycle one rider sits directly in front of the other rider, while both pedal to power the cycle. Many organizations exist that connect blind cyclists with sighted cyclist, enabling the visually-impaired to experience riding a bicycle[6].

In addition to increasing physical fitness for individuals with special needs, cycling provides excellent opportunities for competition as well. Numerous organizations are involved in cycling for individuals with disabilities, and more specifically handcycling competitions. One of most prominent is Paralyzed Veterans of America (PVA). The Paralyzed Veterans Racing Team

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is comprised of paralyzed veterans and other veterans with disabilities that compete at cycling and marathon events nationwide[7]. There are both recreational racers, and competitive racers. For the competitive racer, there are three main types of races. The road race is a mass start event normally between 15-50 miles long that involves tactical skill, and the ability to draft. The second is a time trial where individual cyclists race against the clock and drafting isn't permitted. Riders cover a set distance- usually between 5-15 miles- in the shortest time possible. The final race, called a Criterium, is held on a short circuit which is usually less than 2 miles long. Generally these races are held in a downtown area and have a time limit or pre-determined number of laps. Criteriums are the most spectator-friendly because the cycling "pack" passes by the crowd frequently[5].

In addition to the physical benefits cycling can provide through recreation and competition, medical benefits have been observed due to cycling as well. Studies involving animal research have shown that increased physical activity can produce changes in brain structure and improve performance in many behavioral tasks[8]. Cycling has been shown to provide therapy for multiples diseases and disabilities including Parkinson's disease, Cerebral Palsy, and victims of stroke and paralysis. Additionally, a study was performed to evaluate the effects of adaptive cycling on a subject with Dandy-Walker Syndrome.

Cycling can aid individuals who are newly recovering from stroke by helping to resolve lower limb impairments such as muscle weaknesses. In post-stroke victims, postural imbalance and asymmetric limb movements between the affected and unaffected side are often observed. These irregularities could be caused from inappropriate muscle contraction, muscle spasms, or abnormal muscle activity patterns[9]. Cycling may be used to complement ambulation training in individuals shortly after stroke due to the similarities between biking and walking. Both of these are locomotive activities which involve a flexion and extension of the hip, knee, and ankle. Also, the repetitive motion of cycling allows the body to coordinate muscle synergies, which is important for motor learning. The increased muscle control in the lower limbs resulting from cycling may enable the stroke patient to withstand more weight on the affected leg while standing or walking[10]. Additionally, cycling is an excellent form of therapy because it eliminates the need to balance from the equation and therefore can be more easily used in rehabilitation process.

Strength and motor control deficits are impairments often seen in patients with neurological disorders[11]. Two neurological disorders in particular, Cerebral palsy (CP) and Parkinson's disease (PD), are associated with the therapeutic benefits which come from cycling. Cerebral palsy permanently affects body movement and muscle coordination and is caused by abnormalities in parts of the brain that control motor function. Common symptoms observed in CP are lack of muscle coordination, stiff or tight muscles with exaggerated reflexes, and an irregular muscle tone. Parkinson's disease is a progressive disease of the brain and spinal cord and is associated with difficultly walking, movement, and coordination.[11]

For example, specific bicycle adaptions have been made by EM King in order to target individuals with cerebral palsy[12]. Specifically, the greatest difference observed in cycling technique between a healthy cyclist and one with CP was an early termination of the extension pedal phase during pedaling. A possible reason for early termination and therefore decreased efficiency could be increased hip flexion due to the decreased strength of the hip extensors[11].

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Weakness in hip extensor muscles is believed to be the major culprit in walking impairments in children with cerebral palsy. However, the hip extensors are a very difficult muscle to strengthen. EM King developed a tricycle with added weights which was designed specifically to strengthen the hip extensors, producing a marked improvement in gait. In addition, training on a device that promoted an upright movement pattern likely also contributed to improvements in motor control while walking[12].

Another common neurological disorder, Parkinson's disease (PD), has been the focus of many clinical trials as scientists attempt to determine the positive effect exercise has on the disease. A study by researchers at the Cleveland Clinic found that forced exercise provides a benefit very similar to that of the most effective prescription drug used to treat PD, Levodopa. The results showed that PD patients who exercised on a stationary tandem bicycle during a 40-minute session experienced a 35% improvement in motor function and increased brain activation. Maintaining a pedaling rate of 80-90 rpm showed improved function in the upper extremities as well as the lower extremities, suggesting a global effect in terms of motor function improvement. The Unified Parkinson's Disease Rating scale is a scale developed to follow the progression of PD. Research found that forced exercise (35%) and Levodopa (38%) produced similar reductions in the disease rating scale. These results suggest that exercise and drug treatment may activate similar mechanisms which provide relief from common symptoms of Parkinson's[13].

Finally, the process of building an adaptive cycle was applied to a subject with Dandy-Walker Syndrome as a modified tricycle was designed to meet specific needs. Dandy-Walker Syndrome involves a congenital brain malformation in the cerebellum region of the brain. The cerebellum is the part of the brain which controls motor function and contributes to coordination, precision, and accurate timing of movements. In addition, a cyst may form near the lowest part of the skull, causing an increase in the size of fluid filled spaces surrounding the brain and therefore an increased pressure. Symptoms of Dandy-Walker Syndrome usually occur in early infancy and normally include slow motor development, and muscle stiffness and spasticity. However, Dandy-Walker is a spectral disorder that may range in severity from very disabling to hardly noticeable[14].

Since Dandy-Walker Syndrome is a result of a malformation of the cerebellum, there are understandably impairments in balance, motor control, and coordination of muscle movements. Specifically, symptoms may include developmental delay, low tone (hypotonia), later high tone (spasticity), and poor coordination and balance (ataxia). These symptoms manifest themselves in various ways. Spasticity is essentially stiff and rigid muscles with stronger or exaggerated reflexes and can interfere with walking, movement, and speech. Ataxia is uncoordinated movement as a result of lack of muscle control. It leads to a jerky, unsteady motion of the trunk as well as an unsteady gait[15]. Bicycling can be a therapeutic option for Dandy-Walker patients and serves to strengthen the affected muscles while developing increased motor control and balance.

Methods

There were determined to be four main areas where a patient with Dandy-Walker Syndrome may have weakness or impaired skills. Balance, functional mobility/gait, strength, and coordination were assessed in order to adequately recommend adaptations and modifications to a

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bicycle to meet the special needs of an individual with Dandy-Walker Syndrome. There were numerous tests conducted to help assess the patient's balance, and quantify or classify the degree of impairment. The first was the Romberg test. In the Romberg test, the patient stood with his feet together and arms crossed over his chest with eyes open, then closed for three trials of 60 seconds per trial. The amount of sway was subjectively measured by the observer and marked as unsafe, normal, or minimal. The time that the patient was able to balance in the correct position was measured and recorded. The tandem Romberg test is a more difficult modification of the standard Romberg test where the individual instead stood with one foot directly in front of the other (tandem standing). The same procedure for testing was followed as for the Romberg test.

Another test that was used to specifically assess balance issues in a Dandy-Walker patient is the single limb stance test (SLS). This test is very similar to the Romberg tests, but the patient instead stood on one leg at a time making it more challenging. The patient was instructed to stand with arms crossed on one leg and eyes open, then closed for three trials of 60 seconds maximum per trial. The patient switched to the other leg after completion of the first leg. The amount of sway was again subjectively measured by the examiner. In addition, the amount of time the patient was able to balance in the correct starting position was measured and recorded.

The final test recommended to assess the degree of an individual's balance impairment is the functional reach test. In the standing functional reach test, the patient's stability was assessed by measuring the maximum distance the individual could reach forward while standing in a fixed position. A yardstick was fixed to the wall, level with the patient's shoulder. The patient was first instructed to stand next to, but not touching, a wall and position the arm closer to the wall at 90 degrees of shoulder flexion with a closed fist. The person administering the test noted the starting position of the 3rd metacarpal on the yard stick. The patient was then instructed to reach as far forward as possible without taking a step or moving their feet. The new location of the 3rd metacarpal was then measured and noted. The difference was then calculated between the start and end position of the 3rd metacarpal, which is termed the reach distance. Three trials were performed and the average was taken to ensure accuracy[16]. A study performed in 1990 evaluated Functional Reach (FR) in 128 volunteers and found that age and height are both influencing factors. Functional Reach was found to be a reliable, precise and reasonable clinical approximator of the margin of stability. It may be useful in detecting balance impairment, as well as change in balance performance over time[17].

Functional mobility and gait analysis is another area that was assessed. In the Timed Up and Go Test (TUG) the patient began sitting correctly in a chair, making sure to keep his or her back resting against the back of the chair. A piece of tape was placed three meters directly in front of the chair so that it was easily visible to the patient. On the word "go", the patient was directed to stand up, walk to the line on the floor, and proceed to turn around and walk back to the chair, ending sitting down. The individual was instructed to walk at a normal pace, and the time was stopped when the patient was seated again correctly in the chair.

A more challenging version of the Timed Up and Go Test (TUG) is a variation called the Timed Up and Down Stairs. The patient was instructed to start a foot away from the bottom step and on the word "go" to walk at a normal pace up to the cone placed on the 14th step, turn around, and walk back down to starting position on the ground. The stop watch was started on

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the word “go” and then stopped when the patient reached the bottom step with both feet. The results from three trials were averaged to obtain the most accurate assessment[18].

Coordination may also be affected in individuals with Dandy-Walker Syndrome. Dystaxia is defined as a lack of muscular coordination resulting in shaky limb motions and unsteady gait. It is a type of ataxia and is sometimes described as the inability to judge distance or scale. A few simple tests were administered to quickly and easily monitor arm and leg dystaxia. The Standardized Finger-to-Nose test (SFNT) was used to test for arm dystaxia in individuals with Dandy-Walker syndrome. The patient extended his arms straight out front and was asked to place his finger *directly* on the tip of his nose. The administrator inspected for incoordination or tremor in the movement as the finger approached the nose. This test was performed three times to give the administrator the best picture of the patient’s abilities[19].

A hand-held dynamometer is a device used to measure peak force exerted when resistance is applied. It was used to measure and assess the strength of various muscles and muscle groups. In addition, grip strength is essential to the successful operation of hand brakes on a bicycle and was tested using a Jamar dynamometer. The patient squeezed the handle with a single hand, resulting in the amount of force exerted by the grip on the dial.

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Results

The subject with Dandy-Walker Syndrome was assessed in the areas of balance, functional mobility and gait, coordination, and strength in order to best modify a bicycle design to fit his individual needs. First, the Romberg test and Tandem Romberg test were administered to test his balance. Based on the results shown in Tables 1 and 2, the subject excelled in the Romberg test, but had more trouble in the Tandem Romberg, especially with his eyes closed. General observations were that he tended to sway and naturally hunches over with his head buried. The Single Leg Stance (SLS) test was then performed to increase the level of difficulty. With his eyes open, the patient was able to complete the test averaging around 10 seconds for his right leg, and 4 seconds for his left leg. These differences between the right and left leg show that Dandy-Walker Syndrome may not affect both sides of the body evenly. The SLS test with eyes closed proved to be very difficult as shown by the seemingly sporadic and inconsistent results in Table 3. Finally, the patient performed the Functional Reach Test, and performed exceptionally well. As shown in Table 4, the subject reached over 14 inches each trial. According to published normative data, any reach over 10 inches predicts a low risk of falling and instability.

Table 1. Romberg Test Results

	Trial 1	Trial 2	Trial 3
Eyes Open	1 min	1 min	1 min
Eyes Closed	58.64 sec	53.25 sec	1 min

Table 2. Tandem Romberg Test Results

	Trial 1	Trial 2	Trial 3
Eyes Open	3.72 sec	17.74 sec	9.76 sec
Eyes Closed	2.01 sec	3.62 sec	2.89 sec

Table 3. Single Leg Stance (SLS) Test Results

	Trial 1	Trial 2	Trial 3
Right Leg Eyes Open	17.94 sec	9.89 sec	9.81 sec
Right Leg Eyes Closed	2.26 sec	2.67 sec	1.31 sec
Left Leg Eyes Open	6.71 sec	3.62 sec	3.46 sec
Left Leg Eyes Closed	1.38 sec	0.69 sec	1.27 sec

Table 4. Functional Reach Test Results

	Trial 1	Trial 2	Trial 3
Measured Results:	14 in	17 in	17 in

The subject's functional mobility and gait were tested in a multitude of ways. The Timed Up and Go (TUG) test was administered and the results were reasonably consistent, but were

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slower than average for healthy young adults. The Timed Up and Down Stairs is a similar test, but the patient had more difficultly completing it. Specifically, he had a hard time turning around quickly in a narrow space without support of an arm rail. This observation could be linked to weaknesses in balance and stability. While climbing the stairs, it was observed that he leaned to the left and turned his left foot outwards. The results from both functional mobility and gait tests are shown in Tables 5 and 6. Coordination was the third area tested. In the Finger-to-Nose Test (SFNT) there were no observed tremors, and he had no trouble completing the task.

Table 5. Timed Up and Go (TUG) Test Results

	Trial 1	Trial 2	Trial 3
Timed Results:	12.09	11.47	10.66

Table 6. Timed Up and Down Stairs Test Results

	Trial 1	Trial 2	Trial 3
Timed Results:	17.29	17.17	16.17

Accordingly, the hand-held dynamometer and Jamar dynamometer were used to assess muscular strength. Grip strength was measured using the Jamar dynamometer to ensure proper hand strength to activate the brakes. Although he tested more weak than average, it was determined that his average of 25lb. shown in Table 7 far exceeded the required amount of force necessary to activate the brakes on a bicycle. A set of pre-determined exercises were completed to gauge strength in muscles integral to the cycling motion. The hip abductors, hip adductors, hip flexors, hip extensors (gluteal muscles), knee extensors (quadriceps), and rotator muscles for trunk control were tested. Table 8 shows the full results of the strength testing. It was determined that the crucial areas for improvement were hip strength, ankle strength, and core strength. A strengthening exercise regimen was designed and implemented prior to the individual riding the completed modified cycle. A series of exercises including abdominal planks to strengthen the core, hip abduction movements to increase hip strength, and ankle inversion and eversion exercises using resistance bands were recommended. These exercises were designed to be completed as frequently as possible in order to yield maximum improvement.

Table 7. Grip Strength Testing (JAMAR Dynamometer) Test Results

	Trial 1	Trial 2	Trial 3
Right Hand	26.4 lb.	24.2 lb.	24.2 lb.
Left Hand	35.3 lb.	30.8 lb.	26.4 lb.

Table 8. Hand-Held Dynamometer Strength Testing Results

	Trial 1	Trial 2	Trial 3
Left Knee Extensor	24.9 lb.	22.7 lb.	28.4 lb.

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Right Knee Extensor	24.6 lb.	19.5 lb.	22.5 lb.
Left Hip Flexor	20.5 lb.	16.6 lb.	19.9 lb.
Right Hip Flexor	18.6 lb.	28.4 lb.	23.3 lb.
Right Hip Abductor	18.3 lb.	17.5 lb.	13.1 lb.
Left Hip Abductor	17.3 lb.	14.2 lb.	13.6 lb.
Right Hip Adductor	15.5 lb.	14.3 lb.	16.5 lb.
Left Hip Adductor	14.6 lb.	17.1 lb.	19.3 lb.
Right Hip extensor (gluteus)	20.2 lb.	19.5 lb.	19.4 lb.
Left Hip extensor (gluteus)	21.7 lb.	19.7 lb.	21.1 lb.
Right external rotators	13.7 lb.	18.1 lb.	17.9 lb.
Left external rotators	17.5 lb.	15.5 lb.	13.8 lb.

Finally, the patient’s ability to fluidly complete the cycling motion was assessed by having him ride in two different scenarios. In the first, he rode on a stationary bike with feet constrained to the pedals by foot straps. The resistance was slowly increased on the bike as he pedaled, and a more fluid and smooth cycling motion was observed at the higher resistances. It was observed that his right foot has a tendency to turn outward, causing the heel to come close to the bicycle chain. Next, a standard, upright mountain bike was ridden in a bike trainer with the use of clip-less pedal shoes. A similar procedure was followed as with the stationary bike, as the resistance was gradually increased with time on the bike. The same pattern was observed as his riding motion became more controlled and fluid with increases in the resistance. At the lower resistance the subject seemed to be “getting caught” at a few points in the cycle. The patient’s natural tendency to hunch over and bury his head while riding was also noted. This habit could be due to a core muscle weakness leading to trunk instability. When prompted to look straight ahead, the subject’s cycling movement improved, as did his posture and stability.

Discussion

Table 9. Physical impairments in Dandy-Walker Syndrome linked to bicycle modifications

Physical impairment or weakness	**Bicycle modification implemented**
Impaired balance and stability →	Upright tadpole tricycle with tilting mechanism
Jerky and non-fluid pedaling motion →	Clip-less pedal MTB shoes
Right foot turns outward while pedaling→	Chain guard
Hunched over riding position, weak abdominal muscles →	Wider and more upright bicycle saddle
Hunched riding position and trunk instability and weakness →	Higher and more curved handlebars

The initial benchmark test results were evaluated to translate the physical impairments of the individual into bicycle adaptations necessary to improve bicycle design. These modifications

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were accounted for when building the bicycle that was designed to meet the subject's individual needs. An upright tadpole configuration with the ability to tilt was chosen as the bicycle design to provide maximum benefits for improving balance and coordination. The tilting mechanism can be locked out if needed. Next, a way to constrain his feet to the pedals and prevent unwanted movement was necessary. Based on initial cycling testing, clip-less pedal shoes were determined to be the best option to assist in fluid motion while preventing jerky, side-to-side movement. Mountain biking pedals will assist in ease of walking, since the tread comes down even with the clip. In addition, the clip-less pedal shoes should be easy to unclip from the pedal in case the patient were to lose his balance, tip over, and need to quickly and easily unclip from the bike. The next modification is the addition of a chain guard. It is especially important to have a device cover the right side of the bike where the chain is located since the patient's right foot turns outward. The chain guard will prevent the right leg and heel from potentially getting caught on the chain while pedaling. The bicycle saddle type is another modification necessary. The seat will be wider than a standard bicycle seat, giving some additional support and assistance in sitting upright. Finally, the handlebars will be a little higher, and extend further back towards the rider to encourage engagement of the core. This adaption would hopefully prevent the patient from sitting in a hunched position, and would increase trunk stability and strength. This custom tricycle design and modifications will allow a patient with Dandy-Walker Syndrome to experience the numerous benefits of cycling.

Conclusion/Future Directions

The series of adaptive cycling modifications described above (Table 9) were implemented in the design and construction of a tricycle to be delivered to the test subject with Dandy-Walker Syndrome. The subject will be required to keep a detailed log containing the time, intensity, and frequency of all training rides. After having ridden the fully designed and completed adaptive tricycle for a set number of weeks, the subject will be re-tested using the same benchmark tests administered previously. These post-riding results will be statistically analyzed and compared to the pre-riding assessment to determine the therapeutic nature of the tricycle. It is anticipated that numerous benefits of cycling, specifically gains in balance, coordination, and strength will be evident in the subject with Dandy-Walker Syndrome.

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