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Power Mobility Sensor Data Collection Verified through Standardized Pediatric Assessments

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Power Mobility Sensor Data Collection Verified through Standardized Pediatric Assessments

by

Ayshka Elise Rodriguez-Velez

A Thesis submitted to the Department of Engineering

in partial fulfillment of the requirements for the degree of

Master of Science in Electrical Engineering

UNIVERSITY OF NORTH FLORIDA

COLLEGE OF COMPUTING, ENGINEERING, AND CONSTRUCTION

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DEDICATION

In memory of my grandfather Roberto Velez Colon (Abu).

You motivated & inspired me to continue my education.

This one is for you!

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ABSTRACT

The collaboration between the School of Engineering and the Department of Physical Therapy at the University of North Florida has introduced the possibility of creating a new environment for pediatric physical therapy assessments. There are currently no methods for remotely monitoring children with impairments. However, with embedded sensor technology in the form of power mobility and accepted therapy assessment tools, remote monitoring can become a possibility. As a part of this work, a ride-on toy car was developed as a remote monitoring device and a case study with a child with a mobility impairment was used as a proof of concept. In this thesis, the background information on the project, the case study diagnosis and history, and the model used to develop this project are detailed.

CHAPTER 1: MOTIVATION

Children with developmental disabilities that impair independent mobility often require rehabilitation services such as physical therapy. The therapy services provided are usually based on a one-on-one session with the child in an outpatient rehabilitation setting. This can be prohibitive for parents with limited resources, transportation, and accessibility. If a therapeutic alternative for remote monitoring could be created for use at home that was easy, safe, and fun for the child to use then greater improvements in impairments could be realized.

Impairments responsible for weakened independent mobility can be classified as decreased muscle strength, decreased range of motion, decreased postural stability, and poor weight shifting in postures against gravity. One diagnosis that encompasses these impairments is spina bifida. Children who are born with this health condition have limitations in their functional and emotional maturation and require persistent monitoring.

Improvements in functional skills for these children have typically been monitored through standardized pediatric rehabilitation assessments. A licensed pediatric physical therapist and a parent of the children conduct the assessments. However, it has been acknowledged that pediatric rehabilitation assessments are limited by being strictly qualitative.

Quantitative measurements of postural stability and activity levels of these children are required. A device to monitor children in their own environment would give therapists a remote way to measure improvements of postural sway and activity levels quantitatively. A modified ride-on toy car with embedded sensors was created to test this possibility. A device that can remotely monitor a child in their home environment that is also economical for the patients and their families was fashioned and compared to standardized qualitative assessments for data correlations. This study presents this proof of concept with a single case study.

CHAPTER 2: BACKGROUND

Physical therapy monitoring of children with impairments is conducted intermittently in a clinic throughout the child's lifetime. The occurrence of these visits is dependent on the severity of the condition. During these visits, various tests are conducted to show the level of improvement. These tests consist of hands-on physical assessments, inventory surveys, and performance trials [1]. From these tests, the measure of improvement is determined. However, improvements in the physical function of a child can sometimes be misread. Furthermore, impairments in children can also hinder family mobility. Having to transport the child between their home and the therapy clinic may not always be feasible for the family. Another limitation with clinical rehabilitation is the child's willingness to participate in the associated rehabilitation activities. Children need stimulation and motivation to be accurately tested. To overcome this obstacle, ride-on toy cars have been built to enable children to be independently mobile. This freedom allows children to participate in activities that better their therapeutic goals.

Although these ride-on cars enable children to be mobile and improve in certain functions, there is no form of monitoring on the ride-on cars. The impact of using such power mobility for children with special needs has been reported by many groups to enhance the training abilities of children while exploring their environment [2,16,17]. Sam Logan at Oregon State University has demonstrated through social tests that a child with powered mobility engages more with other children. The socialization of children, with emphasis on the enjoyment of "play", has been the primary focus of pioneer groups such as Sam Logan and Cole Galloway at the University of Delaware and the GoBabyGo organization. Through their studies, power mobility has been shown to have direct impact on a child's enjoyment level [16]. However, these outcomes have all been measured using standardized pediatric therapy assessments, such as the Pediatric Evaluation of

Disability Inventory (PEDI) and the Pediatric Quality of Life Inventory (PedsQL) [16, 25]. These assessments are primary survey tools used to monitor children's progression or regression and are widely used throughout pediatric rehabilitation around the world. Although these assessments are widely accepted, there are some discrepancies in the collection of the data, most stemming from parents' influenced belief of their child's condition or the child's overall willingness to participate.

A collaboration between power mobility play, and physical therapy assessments can help overcome these issues and help determine improvement in children's physical function. The use of embedded sensor technology to measure physical improvements of children has not been explored. There are no reports on embedded sensor technology to remotely monitor a child through power mobility play. The work conducted in this thesis aimed to verify that sensor technology data from a powered ride-on car can be used as part of remote, in-home clinical interventions.

CHAPTER 3: CLINICAL INTERVENTION FOR CASE STUDY

3.1 Spina Bifida

Spina bifida is a neural tube defect. It occurs when the tube formed around the brain and spine does not close properly [3]. There are two types of spina bifida - aperta (meningocele and myelomeningocele) and occulta. Figure 1 shows images of the different forms of spina bifida and the differences in the neural tube defect.

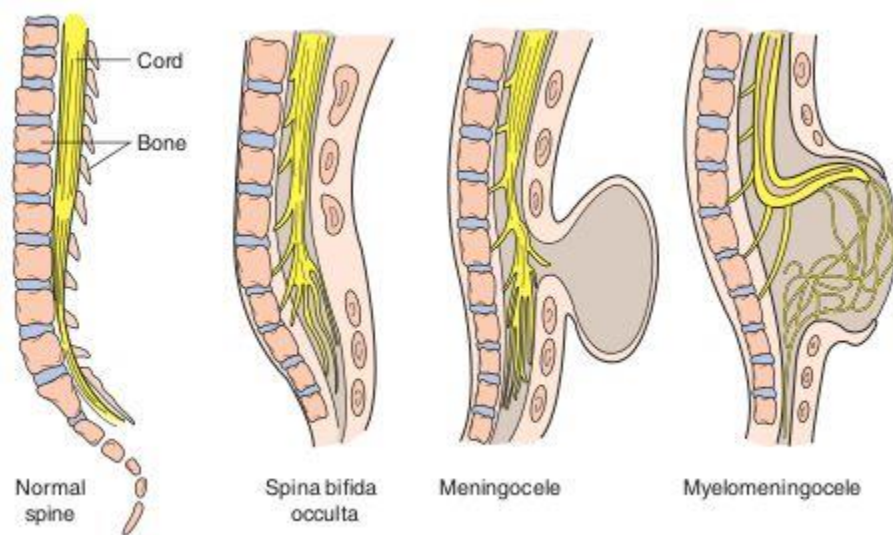


Figure 1: Spina Bifida Types

The most severe condition of spina bifida aperta, Myelomeningocele, occurs when the spinal cord fills the fluid sac and protrudes from the baby's back. The protrusion can occur within any part of the spine. Common side effects of myelomeningocele include, but are not limited to, paralysis or limited function below the lesion level, and loss or limited control of bowel and bladder function.

3.2 International Classification of Functioning Model

The International Classification of Functioning (ICF) Model is accepted by the World Health Organization for understanding how a health condition impacts body structures and

functions, such as muscle strength as well as activity level and participation in life activities such as mobility and play. This model also considers certain environmental and personal factors that may influence the prognosis [5]. The level of functioning of the patient was detailed in the ICF before the device was given to our subject to verify throughout the experimental process. Figure 2 shows the ICF model for the case study. This model was used as a reference for the experimental portion of this thesis.

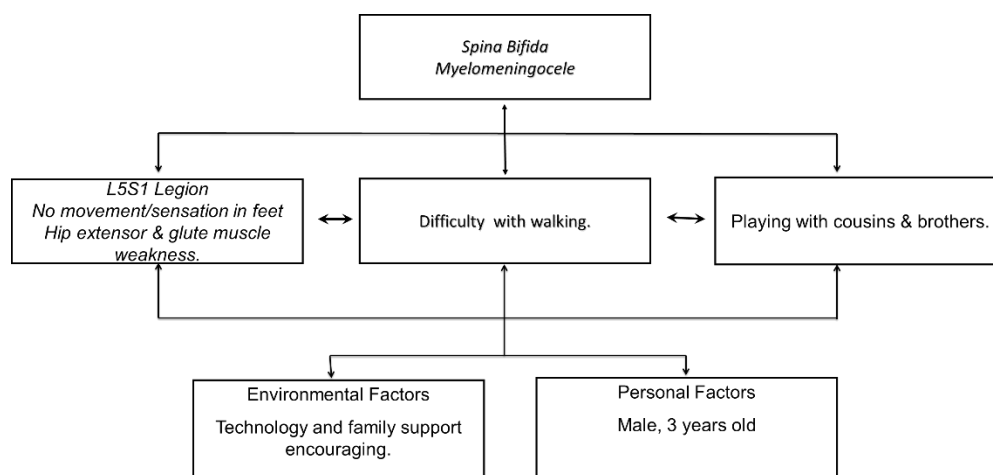


Figure 1: ICF Model for Spina Bifida Patient

3.3 Rehabilitation Management of Condition

Once a child is diagnosed with spina bifida, the only means of repairing the exposure is through surgery. This surgery is usually conducted 24 to 48 hours after birth. After the surgery is conducted, years of physical therapy follow to ensure the best level of functioning can be achieved through physical and emotional improvements. This section will detail some typical rehabilitation management options for a child diagnosed with spina bifida.

3.3.1 Range of Motion & Test

Range of Motion (ROM) measures the flexibility of the body at each joint. Joint flexibility, especially in the lower extremities, allows for ease of walking. A child with spina bifida will have trouble with flexibility in their hips, knees, and ankles. Due to the hindrance of mobility in these joints testing their flexibility is important. There were seven range of motion tests administered in our case study. At the hip joint, there were four separate motions on each side that were tested. These are external rotation, internal rotation, flexion and extension of each hip. For the knee, flexion and extension were tested. On the ankle, dorsiflexion was tested on both sides. A goniometer was used to measure the angle of each of these motions. For each motion there is a normal associated angle that indicates abnormalities. Table 1 shows the typical values for range of motion of the seven motions tested.

Joint	Motion	Angle
Hip	External Rotation	45-60°
	Internal Rotation	45°
	Flexion	120°+
	Extension	20°
Knee	Flexion	135°+
	Extension	0°
Ankle	Dorsiflexion	20°

Table 1: Normal Ranges for Range of Motion Test

If the child is within these angles for range of motion, then the ability to walk should not be hindered. A child with spina bifida will have some variability, but with physical therapy, over time they should improve.

3.3.2 Strength & Manual Muscle Test

The Manual Muscle Test (MMT) is a standardized test that measures the patient's strength [7]. The test was strictly conducted on the lower extremities of the child. The lower extremities

were chosen specifically to note the muscles mainly used for walking and standing. The gravity resisted knee flexion test, which tests the hamstrings, was done by having the child lay on their belly and their knee bent at a 90° angle. The therapist told the child to resist the force placed on the leg. The gravity resisted knee extension test, which tests the quadriceps, was done by having the child sit on a bench with legs dangling. The child held the leg straight up, resisting the therapist pushing down.

Testing hip flexion focused on the iliopsoas muscle. The child sat on a bench and pushed the knee up against the therapist's hand pushing down. For hip extension testing the child laid on their belly, bent the knee at a 90° angle and pushed the leg up towards the ceiling while the therapist pushed down on the foot. Hip extension test primarily examines the gluteus maximus muscle.

The final manual muscle test was the ankle dorsiflexion test. The muscle tested is the tibialis anterior. The child laid flat and kept their foot flexed to prevent the therapist from pushing it down.

The MMT is scored based on a grading scale. The grading scale is from 0 – 5, where 5 is indicative of normal muscle resistance while 0 is minimal to no movement [7]. Table 2 shows the different grading scales and their associated meaning.

Muscle Function	Grades	
No contractions felt in the muscle and no movement	0	Zero
Contraction felt in muscle but no visible movement	1	Trace
Moves through partial range of motion.	2-	Poor-
Moves through complete range of motion	2	Poor
Moves through partial range of motion against gravity	2+	Poor+
Gradual release from test position	3-	Fair-

Holds test position no added pressure	3	Fair
Holds test position against slight pressure	3+	Fair+
Holds test position against slight moderate pressure	4-	Good-
Holds test position against moderate pressure	4	Good
Holds test position against moderate to strong pressure	4+	Good+
Holds test position against strong pressure	5	Normal

Table 2: Manual Muscle Test Grading Scale [7]

The optimal goal is for the child to score a 5. This means full control of muscles that lead to walking. As in range of motion tests, a child with spina bifida lacks strength in these muscle groups which makes it difficult to walk without assistance.

3.3.3 Function & Inventory Tests

Testing for function requires standardized pediatric physical therapy tests that account for more than just physical tests. Quality of life through self-care and emotional steadiness also needs to be monitored. Lack of mobility can hinder a child's overall quality of life. Survey inventories and physical function tests used to measure all aspects of quality of life in pediatrics were explored.

The Pediatric Evaluation of Disability Inventory (PEDI) is a standardized assessment that measures functional performance and caregiver assistance for children between 6 months and 7 years of age [8]. The PEDI tests each measure in three different domains, 1) Self-Care, 2) Mobility, and 3) Social Function. The PEDI is conducted by the primary caregiver of the child, usually a parent or physical therapist. For our case study, the mother was also the physical therapist. To complete the PEDI, several "forced-choice" questions are answered on the child's daily interactions [8].

The PEDI was chosen for assessment of this case study for various reasons. One reason is due to its reliability and validity in pediatric physical therapy practice. The reliability of this survey has been shown to range between 95% - 100% [8]. With such high reliability levels, the outcomes of this assessment are dependable. Another reason for using the PEDI was because of its ability to detect function deficits, monitor individual progress, and evaluate outcomes [8]. It was required for this study to have a method of monitoring progression of a single subject over time, making the PEDI an ideal survey for this experiment.

Like the PEDI, the Pediatric Quality of Life Inventory (PedsQL) is a standardized measurement of quality of life for children between 2 – 7 years of age. There are four components to the PedsQL - 1) Physical Functioning, 2) Emotional Functioning, 3) Social Functioning, and 4) School Functioning. Each assessment targets the problematic level of the child within that domain. For this case study, only physical and emotional functioning were analyzed.

The reasoning behind choosing the PedsQL as an assessment tool was due to its reliability and validity, just like PEDI. For children with chronic illnesses or mobility impairments, quality of life is an important health measure [25]. Treatments are usually monitored as being beneficial through results of the PedsQL.

The PEDI and PedsQL inventories were chosen to monitor the quality of life of the child. The focus of the experiment was physical function. To enhance the Range of Motion and Manual Muscle tests, another test was administered to test walking function. The Timed Up-and-Go (TUG) test measures the walking speed of the child. The reasoning for the TUG test was to determine if the child fell within normal range of walking time based on age. The TUG test measures “basic ambulatory mobility of dynamic balance” [9]. Patients with spina bifida are a primary target for

this test. Equation 1 determines what the TUG, in seconds, should be based on age in year and weight in kg. [10]

$$TUG(s) = 6.837 - [age(y) * 0.166] + [weight(kg) * 0.014] \quad (1)$$

The TUG test is important for a child with spina bifida because the ability to walk is often not possible. This test assists in determining the child's walking ability.

CHAPTER 4: CASE STUDY

The case study for this project is a 3-year-old boy with myelomeningocele. The ride-on car for this child was custom designed for his condition. The purpose of the ride-on car was to provide rehabilitation along with remote monitoring (through embedded sensors) for a yearlong log. The location of the lesion for this case study was the L5-S1 (lumbosacral joint) on the spine. Figure 3 shows the image of the spine indicating the location of the lesion.

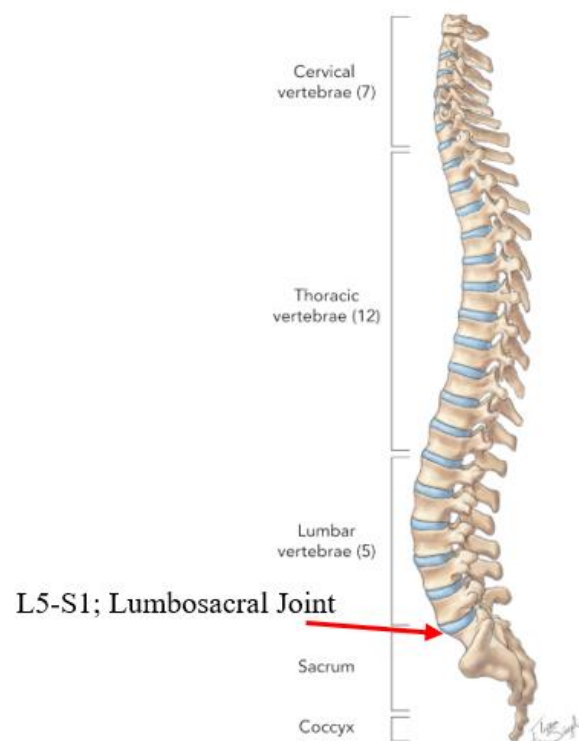


Figure 2: Lumbosacral Joint

Due to the location of lesion level, lower limb paralysis and paresis were present. Upon meeting the child, the ability to ambulate was achieved with the use of an assistive device (a walker). In developing children, the capability to maneuver through the environment is more than simply movement: it promotes the ability to learn, to socialize, and to develop cognitively. While this child had assistive mobility, there was no ability to ambulate independently without an assistive device. The child's ability to ambulate independent of assistive devices was the main goal for the parents and physical therapist.

4.1 Timeline

During the year, a few key observations were made about the child that were necessary for documentation. Various factors contributed to the child's ability and willingness to ride the toy car. One factor was his ambulatory ability. At the first meeting in June 2014, the child maneuvered with the assistance of orthotics and a posterior walker. A posterior walker allows for a patient to walk with a base supported posteriorly (backward) rather than anteriorly (forward). Orthotics are braces used at the joint requiring the most support. Cascade Dynamic Ankle Foot Orthoses (DAFO) 3.5 braces were the braces the child required. The DAFO braces offer resistance in plantarflexion and dorsiflexion of the foot, which assists with excess plantarflexion and knee hypertension. Figure 4 shows the braces and Figure 5 shows the anatomical need for these braces.



Figure 3: Cascade DAFO 3.5 Braces [11]



Figure 4: Excess Plantarflexion & Knee Hypertension [12]

In June 2016, prior to presenting the child with the ride-on toy car, the first formal assessment was conducted. During the assessment it was observed that the child had progressed in assistive device reliance. The child was walking with the assistance of the same DAFO braces but advanced to Walk Easy forearm crutches. The forearm crutches are shown in Figure 6.



Figure 5: Walk Easy Forearm Crutches

The second assessment was conducted in January 2017 after 6 months with the ride-on toy car. During this time, the child used the same assistive devices as in June 2016. However, the child was able to ambulate without the crutches for short distances. The third and final assessment was

conducted in June 2017. At this point, the child ambulated only with DAFO fixed ankle braces set in 5° of plantarflexion with wedged shoes. These shoes allow his shank (leg) vertical angle to be set at 12° and to remove the need for any additional assistive device. An image of this device is shown in Figure 7.



Figure 6: DAFO Fixed Ankle Braces

Tracking the ambulation process was important for the experiment to find a notable difference in the child's postural control. Figure 8 summarizes the child's ambulation timeline for the course of the experiment.

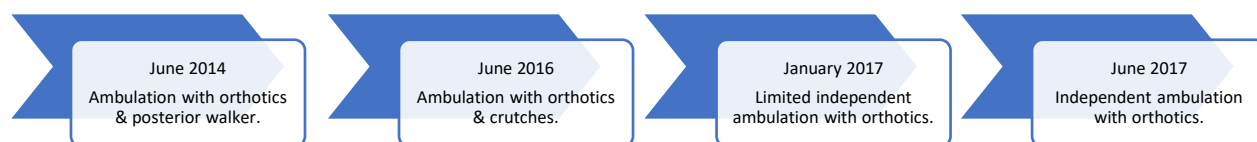


Figure 7: Ambulation Timeline

A factor that negatively attributed to the child's riding enthusiasm was an incident involving a crash. In early October 2016, the child was confident in riding and suggested the car be changed to go faster. The new speed of the car was too fast for the child. It resulted in the child losing control of the car and hitting an object. No injuries occurred nor was any physical damage present. The child did remain hesitant in wanting to ride the toy car a few times post-crash. Lastly,

a factor that attributed to the child's willingness to ride the toy car was surgery. In late October 2016 the child had an appendicostomy. An appendicostomy repairs fecal inconsistencies that occurred due to myelomeningocele [13]. Although the surgery did not limit the child's physical ability to ride the toy-car, the energy level and emotional state were hindered. Having a change in his emotional state did deter the child from wanting to play. These factors were kept in mind while the research and data analysis took place.

4.2 Approach

A shift in a child's weight-bearing from forward weight-bearing to backward weight-bearing indicates improvements in lower-trunk control, which is needed for ambulation. It was proposed as the premise of this study to show that quantitative measurements of weight bearing changes correlate with an increase in quality of life and physical ability of a child, as measured through standardized physical therapy assessments. To this end, the child would play for a year with the ride-on toy car in his neighborhood with his brothers, and once a week, a physical therapy student and an engineering student would visit the family and monitor the progress of the child.

In this thesis, the design approach for the ride-on toy car is detailed, the specifications of the case study experiments are told, and the research methodology analyzed. In Chapter 5, the full modifications of the ride-on car are detailed. In Chapter 6, the experiment is explained through the timeline of the study. In Chapter 7, the data from the qualitative and quantitative methods are clarified. Finally, a conclusion is drawn from the observed data and future work is discussed.

CHAPTER 5: POWER MOBILITY DESIGN

5.1 Ride-On Car Selection

The ride-on car chosen for the child in our case study was based on several factors. One factor was the idea of challenging the child while riding. Due to the child's condition of spina bifida, an ATV style car was chosen, specifically the Power Wheels Kawasaki KFX 12-Volt ride-on in green, shown below. The intended modifications for sensor monitoring and physical therapy challenges were achievable with an ATV style ride-on. To modify the ride-on car, mechanical and electrical changes were made. They will be discussed in detail in proceeding sections.



Figure 9: Powered Ride-On Car Unmodified [14]

5.2 Mechanical Modifications

Major mechanical changes were made to the tires and the steering column. The tires were changed from hollow hard plastic tires to pneumatic traction tires that would allow the car to maneuver on multiple surfaces, especially outdoors. The steering column was altered for data collection purposes that will be discussed in other chapters.

5.2.1 Tires

Pneumatic tires were required for the ride-on to ensure the child could play on multiple terrains. There are seven steps in the process to change the tires from plastic to rubber. The details for this assembly can be found in the Power Wheels with Rubber Wheels manual [15]. Figure 10 shows the store-bought tires compared to the enhanced pneumatic tires.



Figure 10: Unmodified[14] & Modified Front Right Wheel

5.2.2 Steering Column

The modifications to the steering column were required for a few reasons. First, a potentiometer, which measures the steering angle of direction, was attached to the column using a set of gears. Second, the steering column, as it comes from the manufacturer, had very low dimensional tolerance. A slight wiggle during steering was also present causing measurements errors from the sensor.

The first step in modifying the steering column was the assembly of the gear box. The gearbox was printed using ABS plastic material with a Prusa i3 3D printer [26]. It was designed to fit the potentiometer inside with the bottom piece extended with holes for screws. A gear was attached to the top of the potentiometer that protruded from the box slightly and was secured with a pin. The second step was to attach a gear into the steering column itself. This was done by cutting a gear in half and attaching it to the steering column with a pin. Before permanently placing the

gear on the steering column, the gear box that housed the potentiometer was screwed into the ride-on toy car. The gear on the steering column was then placed and tested to ensure full range of handle-bar turning was recorded on the potentiometer.

5.3 Electrical Modifications

The store-bought ride-on car has a simple configuration for the motor controls. A push button is used to make the car go from stop to full speed, another switch allows the car to alternate between slow and fast speed, and a 12-Volt battery powers the toy car. The electrical changes to this ride-on were selected based on the child's physical attributes, the monitoring scheme, and to fit the specific physical therapy intervention. To coordinate all electrical systems, a Raspberry Pi B+ microprocessor (shown in Figure 11) was selected and programmed using Python.

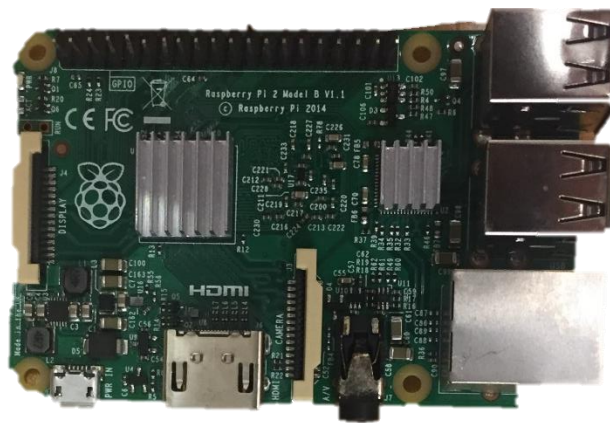


Figure 11: Raspberry Pi B+

5.3.1 Push Button Adaptations

The push button that actuates the ride-on was located on the foot pedal, which made the car unusable by the child due to paralysis in his ankles. From this obstacle, a new design for the push button was created. To challenge the child physically for postural control, a push button on the seat was added. A seat switch would encourage the child to stand on the ride-on while playing rather than to sit down.

As a safety precaution a secondary switch was required. The child was required to stand while on the ride-on car as well as press a secondary switch to make the ride-on car move forward. The secondary push-button switch was added on the handle bar of the steering column. This push button would serve as a safety check to ensure the child was riding the toy car. With these two switch modifications the car would service as both an accessible toy and as a physical therapy tool.

5.3.2 Motor Controller

For a child with limited postural control the sudden change from stop to full speed may be daunting. This is how many ride-on cars operate from the manufacturer therefore a motor-controller was employed to address this issue and provide flexibility in terms of ramping and maximum speeds. A Sabertooth 2x32 motor-controller by Dimension Engineering (shown in Figure 12) was selected for this purpose.

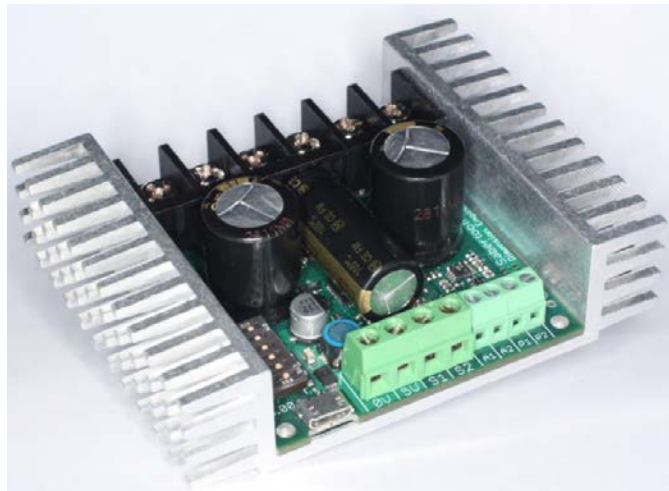


Figure 12: Sabertooth 2x32 Motor-Controller

The rear side of the Sabertooth was connected to the motors controlling the back wheels of the ride-on toy car and to the 12-Volt battery. The front side of the Sabertooth was connected to a printed circuit board and the Raspberry Pi B+ microprocessor. The purpose of this board is explained in later section of the thesis. As previously mentioned, the rationale for the motor-

controller is to limit the maximum speed of the ride-on car and to control its velocity through a ramping function up and down. The Raspberry Pi “tells” the Sabertooth the maximum speed and commands it to ramp up/down. The applied speed is determined by the serial command sent to the Sabertooth. The speed of the ride-on car can be varied from 0 - 7.8 miles-per-hour. The serial communication of the Raspberry Pi varies from 0 to 2047. For a maximum speed of 7.8mph, the serial command is 2047. For walking speed of (3.1mph), the serial command is 813. The speed was maintained at or below walking speed for the duration of this case study. To create a ramping effect on the ride-on car, a simple command was added to the Raspberry Pi to ensure it ramps-up and ramps-down in accordance with the push button configuration. By controlling the motors from the ride-on, the child was able to ride with no jerking and a slower speed allowing for a safe and enjoyable ride.

5.3.3 Pressure Sensors

The purpose of modifying the ride-on for speed was to ensure the child enjoyed the ride and would not be frightened. Creating an enjoyable ride-on toy car will allow for long term use of the device and therefore allow proper data collection through pressure sensors. In this application, adding FX1901 load cell sensors to the ride-on car allowed for real-time monitoring of weight distribution through both feet. To accurately monitor the weight, four sensors were added to two foot-plates designed for accurate data collection. The foot plates were machined to be able to properly fit the pressure sensors and keep the sensors visibly hidden from the child. Figure 13 shows the pressure sensor and the fabricated foot plates design.



Figure 13: Load Cell Sensor & Machined Foot Plate

The load cell sensor takes the applied force and translates it to a differential voltage reading. The load cell sensor reads up to 100lbs per sensor. If the maximum voltage input is 5V, then the differential voltage output for this child's weight would be very small. Due to the small voltage, a printed circuit board (PCB) was designed to enhance the communication between the Raspberry Pi and pressure sensors.

5.3.4 Printed Circuit Board Design

The small output from the load cell sensors created a need for a PCB to improve communication to the Raspberry Pi. Since the Raspberry Pi is not a microcontroller there was no built-in analog-to-digital conversion, which required an external chip. The printed circuit board contained an instrumentation amplifier, an analog-to-digital converter, and connections between all components. Figure 14 shows the final printed circuit board design.

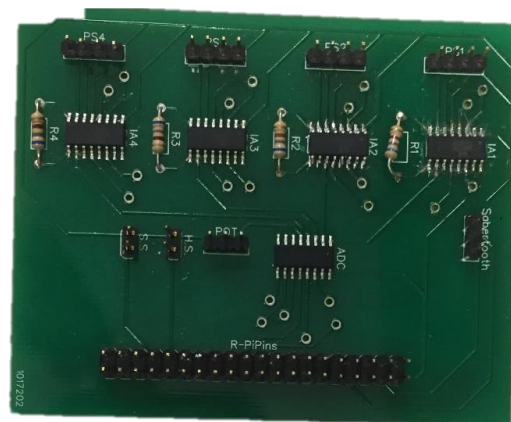


Figure 14: Printed Circuit Board (PCB) Final Design

There were four instrumentation amplifiers for each pressure sensor. Each pressure sensor was amplified by 100. There was one analog-to-digital converter that fed the outputs of the load cell sensors and the potentiometer to the input of the Raspberry Pi. The conversion equation for the analog-to-digital converter is

$$\text{Digital Output} = \frac{(4096 * V_{in})}{V_{ref}} \quad (2)$$

The conversion from the pressure sensors is $1\text{mV} = 1\text{lb}$. The weight conversion is $30\text{lbs} \sim 2457$ digital output. Through this conversion, all weight changes were monitored and recorded on the Raspberry Pi. All modifications made to the ride-on allowed for ease of use for the child as well as proper monitoring of weight shifting throughout each play session. A summary of all modifications is shown in Figure 15.



Figure 15: Modified Ride-on Toy Car

CHAPTER 6: RESEARCH METHODOLOGY

6.1 “Play” Track

At the start of this study, the child independently chose how to play with the ride-on. This allowed the child freedom to choose when to play, where to go, and for how long. Additionally, it provided unbiased data on the child’s preferences. For the first few months the child was observed strictly playing around the cul-de-sac near his home, but gradually began to explore past his comfort zone. Once he was confident enough to leave the cul-de-sac, a track was implemented to have a level of consistency in the data being collected. The track for the remainder of the case study was 0.4 miles around the neighborhood and is shown in Figure 16.

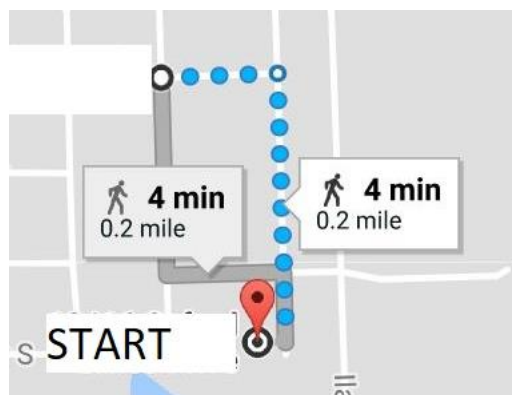


Figure 16: Experiment Track

While the child maintained the above track for most of the experiment, not all days were the same. By having the freedom to choose how to play, the child would continuously change whether he drove up or down driveways, whether he would play games that challenged his posture, or whether he just did not want to play. Although this created inconsistencies throughout the experiment, a more accurate representation of the child’s daily life was achievable. After every play session, the data was taken directly from the ride-on.

6.2 Physical Therapy Data Collection Process

The collection process for the standardized physical therapy data was conducted by the child's parents. It is noted that the child's mother is a pediatric physical therapist. The PEDI and the PEDsQL were completed three times: June 2016 as the pre-assessment, January 2017 as a 6-month follow-up, and June 2017 as a 1-year follow-up. The father or the mother filled out the survey intermittently. This created some inconsistency in the completion of the forms throughout the year, however it was not significant to the results. The physical assessments were conducted after January 2017. The three physical assessments were chosen to enhance the validity of the child's postural stability over time. The child's mother performed each test at the home. The first test was conducted in February 2017 and the follow-up was in October 2017. With the addition of these tests, the ride-on car data could be correlated with more precision.

6.3 Ride-On Toy Car Data Collection Process

To maintain safety of patient information, wireless communication was not added to the Raspberry Pi. The data was directly stored into the Raspberry Pi as a .csv file that was easily converted to an excel file. The excel file contained the time stamp for each data point collected, the four recorded pressure sensors, and the potentiometer steering. Each trial consisted of one visit to the family. The SD card was taken from the ride-on car and inserted into a different raspberry pi that was connected to a monitor. The files were copied from the documents folder on the Raspberry Pi onto a USB drive. The data was then transferred to a laptop and taken for analysis. This process occurred at every session for the year long duration of the experiment.

CHAPTER 7: RESULTS

The objective of this study was to determine a correlation between standardized pediatric physical therapy assessments and quantitative data obtained from the sensors in the ride-on toy car. Before a correlation between qualitative and quantitative data could be made each test was looked at independently to monitor changes throughout the course of the experiment.

7.1 Standard Physical Therapy Methods

The PEDI evaluates: 1) functional skills and 2) caregiver assistance by looking at 1) self-care and 2) mobility of the child. Functional skills detail the child's personal growth in self-care and mobility, while caregiver assistance details the need for parental intervention. Self-care is expressed as any task required in a daily routine, i.e. brushing teeth, putting on clothes etc. The requirements for mobility are determined by the child's ability to maneuver through daily tasks, from requiring transportation to walking up and down stairs. Based on the data collected, the Functional Skills Scale results were plotted in Figure 17 and quantified in Table 3 [16]. The green arrow is used to indicate that an increase in percentage signifies improvement in functional skills.

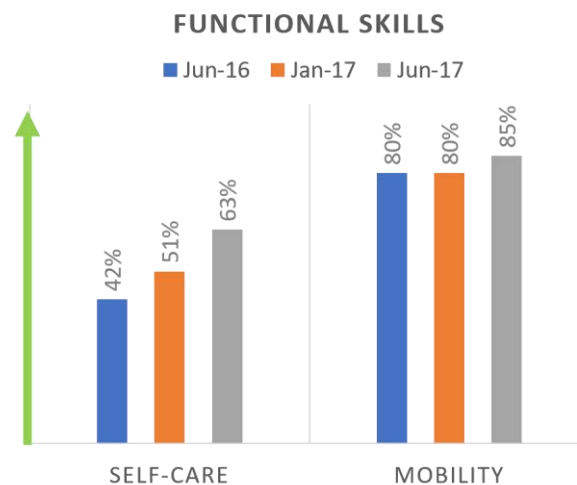


Figure 17: Functional Skills Assessment Results

Date	Functional Skills Scale Scores	
	Self-Care	Mobility
June 2016	42.5	79.7
January 2017	50.7	79.7
June 2017	63.0	84.7

Table 3: Functional Skills Assessment Results Values

As in functional skills, caregiver assistance monitors the level at which the child needs assistance. Based on the data collected, the caregiver assistance was plotted in Figure 18 and quantified in Table 4. The green arrow in Figure 18 is used to indicate that a decrease in percentage signifies improvement, and therefore greater independence of the child.

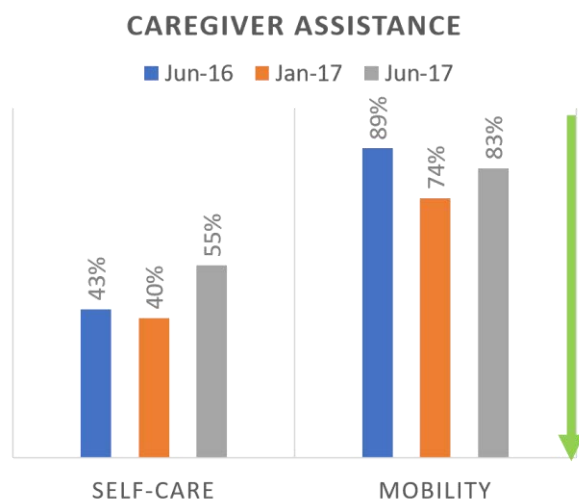


Figure 18: Caregiver Assistance Assessment Results

Date	Caregiver Assistance	
	Self-Care	Mobility
June 2016	42.5	88.6
January 2017	40.0	74.3
June 2017	55.0	82.9

Table 4: Caregiver Assistance Assessment Results Values

These results clearly indicate that for functional skills there was an increase in both self-care and mobility from June 2016 to June 2017, and for caregiver assistance there was an increase in self-care but a decrease in mobility for the same period. These results were further analyzed to

determine if these observed changes are clinically significant. The difference (increase or decrease) in each data collection was compared to the clinically significant benchmark of 11% which ranges from 6 to 15 points for all PEDI scales [20]. A difference of 11% up or down in the child's overall score has clinical significance in the improvement or regression of their condition. The benchmark difference of 11% was determined from a large study of children under the PEDI criteria in 1996 [8]. From the study this method of comparison has been used as the reference point for PEDI analysis. Table 5 shows the PEDI data differences based on the collected data.

PEDI		Jun '16 – Jan '17	Jan '17 – Jun '17	Jun '16 – Jun '17
Functional Skills	Self-Care	+8.2	+12.3	+20.5
	Mobility	0	+4.3	+4.3
Caregiver Assistance	Self-Care	-2.5	+15	+12.5
	Mobility	-14.3	+8.6	-5.7

Table 5: PEDI Calculated Differences

From the data collected for functional skills and caregiver assistance, there were noticeable significant differences. It can be said that self-care in functional skills had a drastic increase. Self-care in caregiver assistance had a large increase in the first six months of the experiment. Mobility in caregiver assistance had a large decrease. The results from the PEDI concluded that the child had improved in his ability to care for himself. The increase in self-care from caregiver assistance can be attributed to the surgery that occurred in October 2016. The large decrease in caregiver assistance in mobility expresses the child's decrease of dependence on the caregiver for mobility within the first six months of the experiment.

The next inventory test conducted was the PEDsQL, where physical and emotional functioning are measured. Figure 19 and Table 6 show the results for the assessment collections.

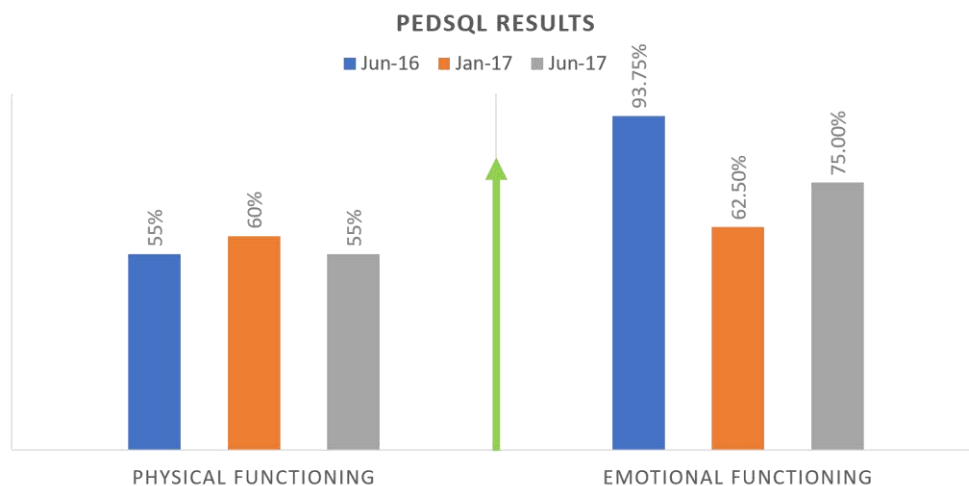


Figure 19: PedsQL Results

Date	PedsQL Results	
	Physical Functioning	Emotional Functioning
June 2016	55%	93.75%
January 2017	60%	62.5%
June 2017	55%	75%

Table 6: PedsQL Percentage Results

The PedsQL works as the PEDI, where an increase in function is considered an improvement. To determine whether there was any significant change in the results over the course of the experiment a minimal clinically significant difference had to be determined. These differences were determined for physical functioning to be $\pm 6.76\%$ and for emotional functioning $\pm 10.37\%$ [25]. Clinically significant values for the PedsQL are a standard of measure for analysis that were determined from studies conducted on a large sample of children [25].

		Jun '16 – Jan '17	Jan '17 – Jun '17	Jun '16 – Jun '17
PedsQL	Physical Functioning	-5%	+5%	0%
	Emotional Functioning	-31.25%	+12.5%	-18.75%

Table 7: Minimal Clinically Significant Difference Calculations

For the PedsQL, there was no significant change in physical functioning, but large increases and decreases in emotional functioning throughout the year were significant. Over the course of the experiment the emotional function of the child varied. The decrease in emotional function from June 2016 to January 2017 can be attributed to the surgery in October 2016. The increase from January 2017 to June 2017 can be correlated with the child's increase in independent mobility. The decrease in emotional function overall can be attributed to the child's awareness of his condition as he grows up. The trend of emotional functioning follows the trend of the PEDI caregiver assistance in both mobility and self-care.

The physical assessments of the child were conducted twice from February 2017 to October 2017. Each test was conducted and analyzed searching for improvements. The results for range of motion tests indicated a dramatic increase in hip external rotation. The hips went from less than normal to excessively, externally rotated. This increase leads to believe that the child can now stand straighter. Although hip extension remained weak, it did get better within the 8-month span of data collection. Knee flexion and extension showed no significant improvement. Dorsiflexion got better over time. Since the child has paralysis in the ankles, the increased range of motion to nearly normal on the left shows an improvement in ankle motion. These results are quantified in Table 8.

Range of Motion Test & Side	Normal Range	02/25/2017		10/12/2017	
		Right	Left	Right	Left
Hip Internal Rotation	45-60°	68°	70°	75°	80°
Hip External Rotation	45°	36°	30°	80°	70°
Hip Flexion	120°+	Full	Full	145°	148°
Hip Extension	20°	0°	-3°	5°	5°
Knee Flexion	135°+	150°	150°	150°	150°
Knee Extension	0°	0°	0°	-5°	-5°
Dorsiflexion	20°	2°	2°	5°	15°

Table 8: Range of Motion Test Results

The results for the manual muscle test indicated that ankle and hip flexion and extension did not show any improvement. In addition, knee flexion on the left side improved along with knee extension. The improvements in the knee flexion and extension are indicators for postural improvement. However, the lack of muscular improvement in the hips when compared to the improved range of motion contradicts the improvement of postural control. These results are tabulated in Table 9.

Muscle Test & Side	02/04/2017		10/12/2017	
	Right	Left	Right	Left
Hip Flexion	5/5	5/5	5/5	5/5
Hip Extension	2/5	2+/5	2/5	2+/5
Knee Flexion	4-/5	4-/5	4-/5	4/5
Knee Extension	4+/5	4+/5	5/5	5/5
Ankle	0/5	0/5	0/5	0/5

Table 9: Manual Muscle Test Results

Finally, the Timed Up-and-Go Test (TUG) was conducted. Based on the child in our case study and the previously explained formula (Equation 1) the TUG test result should be 6.589 seconds. The results obtained from the TUG tests are shown in table 10.

Date	02/25/2017	10/12/2017
Time (sec)	5.76	4.10

Table 10: Timed Up-and-Go Test Results

These results are both less than the calculated time for the TUG test. In addition, there is an improvement of 1.66 second between both dates. It is concluded from these results that postural control is present. Although no increase in hip extension in muscle was present, the increase in hip external rotation and a TUG time less than normal are strong indicators that the child possesses good postural control.

7.2 New Methodology Based on Sensor Technology

The goals for the quantitative analysis were to monitor the child's weight shifting over time and to determine if there was a correlation between the quantitative and qualitative results. A graph of cumulative trial times versus cumulative number of stops was employed for this and is shown in Figure 20. The cumulative number of stops corresponded with the number of times the child pressed or let go of the handle bar push button added per trial. The cumulative trial times was the length of each visit added per trial. The cumulative data graph shows a steady increase in time versus stops. From the graph it can be inferred that the child's confidence level on the four-wheeler is proportional to his postural control.

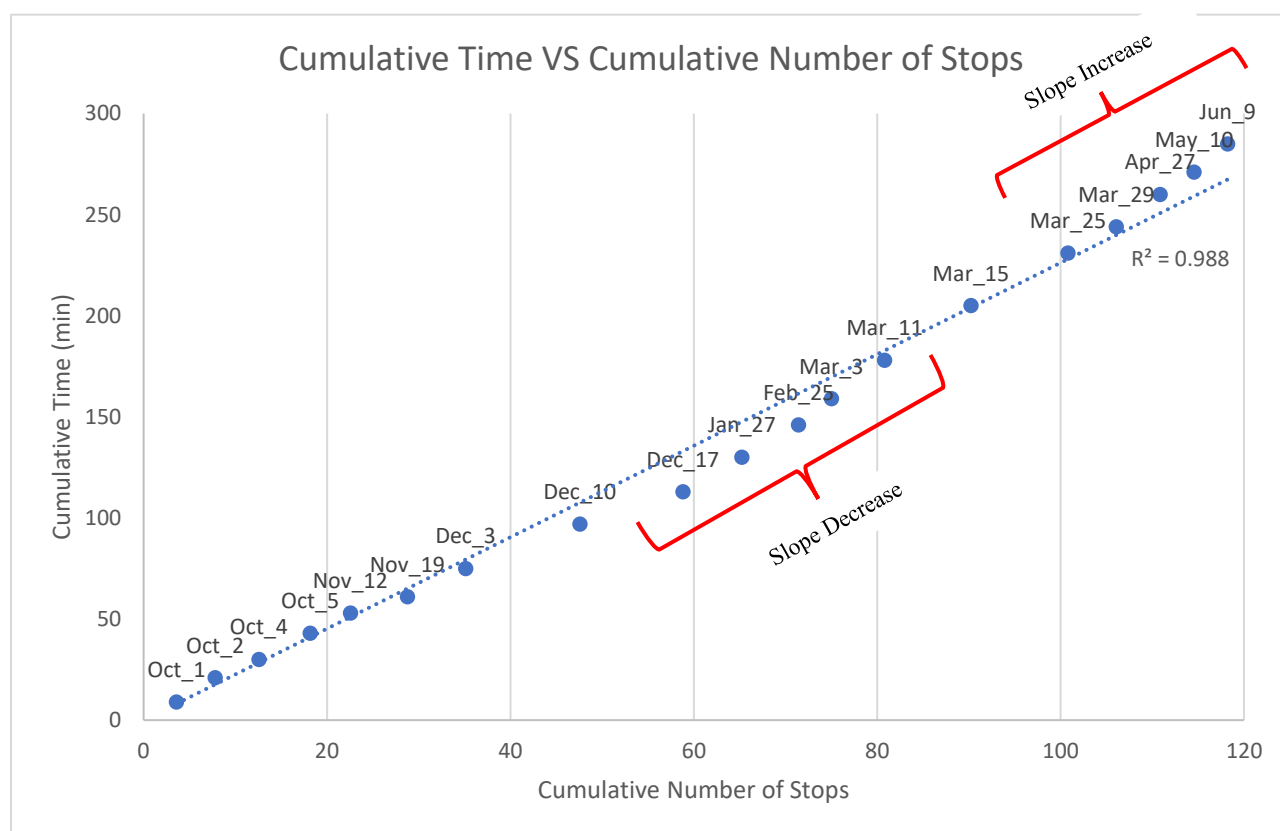


Figure 20: Cumulative Trial Graph

A tendency noticed from the cumulative trial graph is the change in the overall trend. Although the trendline is seemingly linear, there is a dip in the linearity around the six months mark, between December 10 and February 25. This data can be correlated to the pressure sensors data and to life events in the child's life to reveal effects in the physical therapy intervention.

The weight shifting data from the pressure sensors was collected to determine whether the child would eventually shift toward the heels versus the balls of the feet. Such rear shifting would indicate increased postural stability. As discussed previously, the hips pushing forward or rotating externally forces the weight to shift back on the heels. Since there was a dramatic increase in external hip rotation, it can be expected that the pressure sensor data would also indicate this behavior. Furthermore, an increase in confidence in the ride-on toy car is also an indicator of weight shifting. As the child relies less on the upper body to support his posture, more of the weight will be shifted from the steering handle bars onto the feet plates. Figure 21 shows the total weight distributed on the feet plates and categorized as left or right and ball or heel.

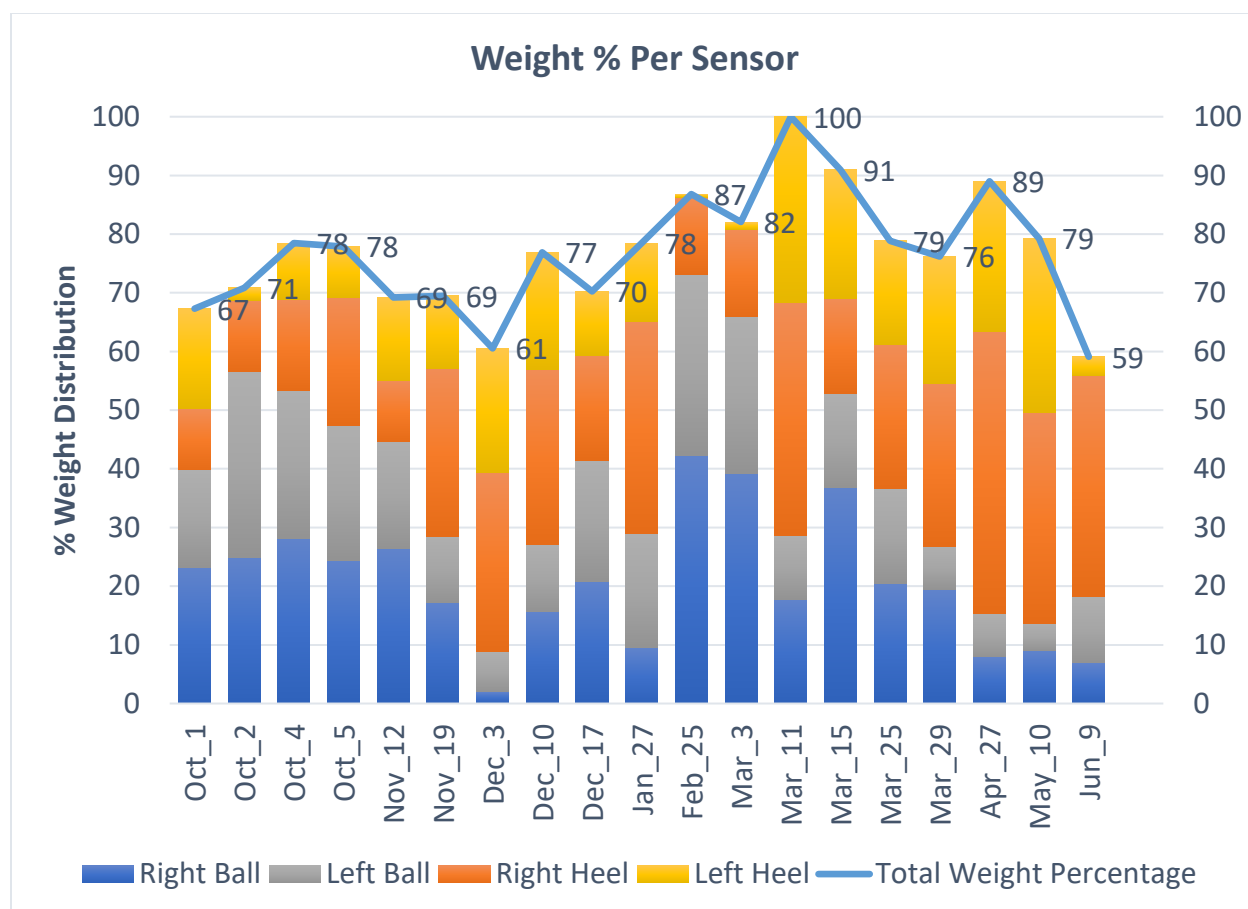


Figure 21: Weight Distribution Graph

At the start of the experiment, the child was placing most of the weight on the balls of the feet with no preference to right or left. The weight began to shift backwards between November and December. Between January and early March, the weight distributed completely forward. From mid-March until June, most of the weight was on the heels and more of the total weight was on the feet plates. The change in weight shifting from heels – balls – heels follows the same trend as the cumulative trial graph. The graph also shows that near the end of the experiment the child was putting more of the weight on the feet plates than on the handle bars. This trend shows the increase in confidence on the lower body than on the upper body.

The final analysis computed on the quantitative data was a validity test to validate the operation of the pressure sensors. A correlation test between each pressure sensors was done to

ensure that the recording was behaving as anticipated. Table 11 shows the correlation test between the pressure sensors.

Correlation					
Right Ball – Right Heel	Left Ball – Left Heel	Right Ball – Left Heel	Right Heel – Left Heel	Left Ball – Right Ball	Left Ball – Right Heel
-0.739	-0.755	-0.432	0.571	0.737	-0.704

Table 11: Correlation Test

From the correlation test there is a positive relationship between the heels of the feet and the balls of the feet, while there is a negative correlation between the other relationships. These results validate the operation of the pressure sensors.

CHAPTER 8: DISCUSSION

Over the course of this study, the child improved in physical function and reached the milestone of being able to walk with limited assistive devices. The results that clearly revealed this increase in walking function were collected using the ROM test, the MMT, and the TUG test. Furthermore, results from the weight-distribution graph (Figure 21) correlate with these tests. An increase in external hip rotation and a TUG time less than the minimally significant time lead to a conclusion of good postural control, although no substantial increase in muscular hip extension was present. The postural control necessary to stand upright requires a weight distribution change from weight-bearing on the balls of the feet to weight-bearing on the heels of the feet. Such weight distribution was measured using the pressure sensors in the ride-on car. These results indicate that the child went from applying 41% of his weight on his heels to placing 66% of his weight on his heels. Additionally, there was an increase from 72% of his total body weight on the pressure sensors to 82%, indicating less reliance on his hands/handle bars and more on his feet. Hence, it is noted that both tests (quantitative or sensor based, and qualitative standardize assessments) detect this change.

The trends between the PEDI, the PedsQL, the cumulative graph, and the weight distribution graph also display correlation. Each trend shows a depression around January 2017, the six-month mark. The PEDI caregiver assistance and the PedsQL emotional functioning depression shows that the child's surgery had an impact on his quality of life. The cumulative graph and the weight distribution graph also shows a depression during the January 2017 time frame. Although the cumulative graph and the weight distribution graph do not give specific causes for the depression, it is noted that a deviation in trend has occurred, indicating a change in the

child's life. As a proof of concept for a remote monitoring device this deviation in trend indicates to the therapist that a closer look at the intervention and to the child in general is necessary.

CHAPTER 9: CONCLUSION

The purpose of this study was to determine whether a correlation was present between standard, commonly employed pediatric physical therapy assessments and a remote monitoring device in the form of a modified ride-on toy car. Based on the collected results, it is concluded that it is possible to have remote, quantitative monitoring of a child through a ride-on car. This is an important conclusion with potential impact for remote rehabilitation (e.g. telemedicine) interventions and the future prognosis of children with disabilities who would benefit from such interventions.

RECOMMENDATIONS

Suggestions to expand the usability of the ride-on toy car as a remote monitoring device are described throughout this section. Types of pediatric physical therapy assessments should exceed the types listed in this paper. This recommendation is due to the requirement of hands-on physical therapy assessments from the beginning of the project. Having a balanced list of assessments to be conducted from the start of the experiment is important. To ensure there are no discrepancies in the survey assessments, the same parent should fill out the forms and a physical therapist who is not the parent should also conduct all the hands-on assessments. It is recommended that these steps be taken and recorded throughout the duration of the project to eliminate any inconsistencies or biases.

Recommendation for the building and design of the ride-on car should be done with an Arduino microcontroller instead of a Raspberry Pi microprocessor. Although a microprocessor can be a more powerful tool, the needs for this project are easily met with an Arduino-based microcontroller. The use of pressure sensors on the handle bars as well as the foot plates for total weight distribution measurements is an important addition. Having the measurement of weight displaced on the handle bars will allow for a precise total body weight distribution. The pressure sensors should continually record weight distribution even when no movement is occurring. Knowing the weight distribution of the child when no movement is occurring on the ride-on presents the data of static motion. Static motion can give important indicators to the postural stability of the child. These modifications on the build of the car allow for easy data interpretation and analysis.

For the experiment, data should be recorded and obtained at least once a week. Maintaining accountability of at least one riding session a week is important for fluidity of data collection. If

changing speed is a goal, then providing slight increases will ensure the child will be challenged without being frightened. The changes should occur in a strategic manner throughout the year long experiment.

With these alterations, the data collected from the ride-on toy car could be used to determine inconsistencies with the child's postural control precisely, rather than a vague determination of an issue.

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Publications

Mary Lundy, **Ayshka Rodriguez**, Juan Aceros, “Engineering, Physical Therapy and the Community: A Service Learning Course,” 40th Eng. in Med. and Biol. Conf., July (2018) – Under Review

Lundy M, **Rodriguez-Velez A**, Aceros J. Modified Ride-On Toy Cars With Proportional Joysticks For Children With Multiple Complex Disabilities: Technical Report. Submitted to Pediatric Physical Therapy. Under review with revisions requested.

Poster Presentations

Rodriguez A, Lundy M, Aceros L, St. Germain E, Kreidl, O. Functional activity monitoring through embedded sensors in a modified ride on toy car. *Presented at RESNA 2017 Annual Conference: AT Innovations Across the Lifespan in New Orleans June 26-30, 2017.*

Rodriguez A, Emord N, Aceros J, Lundy M. Early-Childhood Exploration and Cognitive Development. *Presented at the 6th Annual Florida Undergraduate Research Conference, February 2016, Tampa, FL.*

Awards

Albert D Ernest Caring Award

Fall 2016

Outreach Medallion Award

Spring 2016