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Use of Functional Electrical Stimulation for Functional Mobility of a Pediatric Patient with Cerebral Palsy: A Case Report

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Abstract
Background: Children with cerebral palsy (CP) have varying impairments of motor control and muscle tone, impacting functional mobility. One physical therapy intervention for children with limited functional mobility is utilizing functional electrical stimulation (FES) as an intervention to facilitate movement. FES cycling and FES assisted tasks are becoming more readily studied and utilized as an intervention for this population of patients. To date, there are few studies that evaluate the use of FES interventions combined with land based interventions in children with spastic quadriplegic CP. **Purpose:** Discuss the use of FES cycling and aided functional activities as an intervention for a pediatric patients with spastic quadriplegic CP. **Intervention:** During a four-week timeframe, a five-year-old boy with spastic quadriplegic CP, participated in physical therapy sessions one time per week utilizing FES cycling and FES assisted functional activities and one time per week utilizing adaptive cycling and non-FES assisted activities. The RT300 FES cycling machine was utilized, as well as the portable SAGE controller component of the RT300 for functional tasks of supine bridging, sit to stand, and static standing. **Outcome Measures:** Data points from the RT300 were utilized to track objective changes between each session of FES cycling. Qualitative data comparing the level of physical assistance required with each functional activity was utilized to track changes between FES and non-FES sessions each week. **Discussion:** FES cycling and FES assisted activities may provide feasible and well-tolerated physical activity interventions for children with spastic quadriplegic CP. A multi-modal intervention approach with FES and non-FES activities may provide variety and opportunities for motor learning in the pediatric setting.

Keywords: Pediatrics; functional electrical stimulation; FES; quadriplegic cerebral palsy; bicycling; physical therapy

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Background and Purpose:

As children develop, they strive to excel in many areas of the developmental process, including cognition, social and behavioral skills, and functional mobility. Children with cerebral palsy (CP) are born with an additional barrier to developing functional mobility skills, due to having a static impairment of the brain that impacts movement and muscle tone. CP is the most common motor disability in the pediatric population[1]. CP impacts a child's functional mobility, as well as their ability to participate and function. Individuals with CP have various levels of functional mobility impairments, ranging from barely noticeable to profound mobility impairments.

The etiology of CP is multi-factorial and causes are numerous, accounting for the wide range of mobility impairments[1]. CP is due to an abnormality in the brain that is acquired early in a child's life, prenatally, perinatally, and/or postnatally, causing a static abnormality of the child's brain. Various risk factors play a role in the development of CP, including birth weight, gestational age, encephalopathy, multiple pregnancy, infection and inflammation, and other genetic factors[1]. CP presents as one of four types, spastic, dyskinetic, ataxic, hypotonic, or a combination of these types, depending on the area of the brain that has been damaged[2]. CP is also classified by the number of limbs involved (quadriplegic or diplegic) or if only one side of the body is involved (hemiplegic). Of all individuals with CP, 88% have a form of spastic CP[3]. One form of spastic CP is quadriplegic CP, impacting all four extremities. In order to aid in the understanding and classification of the varying levels of functional mobility of individuals with CP, the use of the Gross Motor Functional Classification Scale (GMFCS) has been used to aid in classifying levels of mobility and predicting future functional mobility. Additionally, this scale is utilized to predict future assistive devices and means of mobility that a child may use in the future based on their current level of functional mobility[4].

For individuals with GMFCS levels I-III, in which walking abilities are available to moderately limited, more intervention options are available due to the higher level of function these individuals have. A recent meta-analysis reported a medium effect size indicating support for the use of electrical stimulation as an intervention for children with CP and associated gait problems such as walking impairments and activity limitations[5]. This study found that both functional and neuromuscular electrical stimulation treatments helped to minimize impairment and activity limitations in walking[5].

Individuals with a GMFCS level III-V have moderately to maximally limited gait abilities, therefore quantifying physical activity and outcome measures can be difficult. Selecting age-appropriate, feasible, and beneficial physical therapy interventions to address impairments of gross motor skills, strength, and gait abnormalities can be difficult when working with this patient population. Electrical stimulation has been found to be an effective modality for improving muscle strength, improving blood flow, decreasing atrophy, decreasing pain, and aiding in tissue healing in individuals with neurological damage[6]. One form of utilizing electrical stimulation is functional electrical stimulation (FES), which refers to the process of pairing the stimulation simultaneously or intermittently with a functional task[6]. FES cycling has been shown to be feasible and well-tolerated for individuals with CP in various case reports[7-9].

Recent case studies have utilized FES cycling for individuals with CP and found the treatment to be safe, feasible and well-accepted by participants[8,9]. Due to the heterogeneous nature of CP and variations of treatment dosage among case studies, the exact dosage of FES cycling as an intervention for children with spastic quadriplegic CP has not been clearly defined in recent literature[8,9]. Although previous studies have identified the difficulty in defining the dosage and balance of utilizing FES cycling, they have found benefits[8,9].

Finding effective and age-appropriate intervention programs that meet physical activity guidelines for children with CP with moderate to severe gross motor limitations has been a challenge for researchers and physical therapist[9,10]. Utilizing FES cycling, FES assisted functional activities, and non-FES activities is a proposed physical therapy intervention method for a child with spastic quadriplegic CP. This case report will aim to focus on the use of FES cycling and FES assisted functional activities during a four-week timeframe for a five-year-old pediatric patient with spastic quadriplegic cerebral palsy.

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Case Description: Patient History and Systems Review

A five-year-old boy with an extensive medical history and primary medical diagnosis of spastic quadriplegic CP began a new episode of physical therapy care in an outpatient pediatric clinic following a recent hip surgery. The patient had an extensive medical history consisting of preterm birth with a twin sister via emergency caesarian section at 28 weeks, a twelve week stay in the Neonatal Intensive Care Unit after birth, and resolved history of torticollis and plagiocephaly. Additionally, the patient had two intracranial bleeds in his frontal lobe at birth, in addition to a brain malformation of colpocephaly. The patient's surgical history includes bowel resection, selective dorsal rhizotomy (SDR), and hip surgery. Details of the patient's surgical history were not well defined according to the patient's current physical therapist. The patient's current list of additional medical diagnoses includes mild patent ductus arteriosus, exotropia, and esotropia. All of the patient's developmental milestones were delayed, and he has a long-standing history of participating in multiple episodes of care of physical therapy from birth to present day.

The patient had participated in additional therapies throughout his entire life, including speech, occupational, vision, and mental health therapies. During the timeframe of this case report, the patient was participating in physical, occupational, speech, and mental health therapies. Additionally, the child was attending public school part-time with modifications to accommodate to the patient's physical and mental abilities. The patient had a history of utilizing a standing frame and gait trainer at school, as well as currently utilizing a standing frame for about two hours per day at school. Due to extensive delays in developmental milestones and they unique nature of spastic quadriplegic CP, the child had been dependent with all transfers throughout his life. As a means of mobility, the patient had been utilizing a manual wheelchair with the ability to self-propel small distances, however primarily relied on others to propel most home and community distances.

The patient's family expressed that their primary physical therapy goal throughout the patient's life had been to maximize his functional mobility to allow for him to have the greatest quality of life. The family also expressed hopes and dreams for their child to gain as much strength and mobility possible given his diagnoses. The family's goals had been addressed throughout the course of the patient's previous and current episodes of physical therapy care.

Examination:

The patient participated in physical therapy throughout his entire life, including care in different states and various inpatient and outpatient therapy clinics. The patient began physical therapy care at his most recent outpatient pediatric clinic when he was three years and six months old. The patient's initial examination showed that the patient was utilizing a manual wheelchair, gait trainer, and bilateral ankle foot orthoses (AFOs). Upon initial evaluation, the patient presented with impairments of increased muscle tone, grossly reduced bilateral upper and lower extremity strength, poor static and dynamic balance, and poor protective reactions. The patient participated in multiple episodes of care to address these impairments.

The patient had a history of participating in a bout of physical therapy utilizing FES cycling on a RT300 cycling machine and FES stepping on a RT600 machine. The patient's current physical therapist and the patient's family reported positive outcomes following the introduction of utilizing FES interventions. The use of FES interventions were put on hold after the patient underwent hip surgery and extensive inpatient rehabilitation, in which details were unclear.

This case report focused on a four-week timeframe in the patient's most recent physical therapy episode of care, in which the patient began the reintroduction of FES cycling and FES assisted activities. Prior to re-starting FES interventions, the patient underwent one month of land based therapy with therapy goals focused on improving sitting balance, level of independence with sit to stand transfers, standing strength, lower extremity strength and endurance, and core strength. Land based therapy interventions included utilizing an adaptive tricycle and therapist assisted bench sitting, supine bridging, and sit to stand transfers. At this time, the patient was dependent with all transfers, wore bilateral AFOs, and utilized a manual wheelchair in which he was able to self-propel small distances

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and required maximal assistance for community and most home distances. The patient's mother reported that he was able to utilize a modified crawling method to progress himself on the floor for aout100 feet. Prior to reintroducing FES interventions, the patient required moderate (50%) to maximal (greater than 75%) assistance to complete a sit to stand transfer, stand for 2 minutes, complete a supine bridge, and pedal an adaptive tricycle greater than 200 feet. The patient required minimal (less than 25%) to moderate assistance for sitting on a bench with feet on ground and bilateral ankles, knees, and hips at 90 degrees of flexion. The patient could statically sit on a bench for three seconds with close stand by assistance at this time.

The patient was five years and ten months old when FES interventions were reintroduced into his treatment plan and this case report highlights the first four-weeks of utilizing FES interventions and non-FES interventions. The patient's primary physical therapy goals during this timeframe were to improve lower extremity strength for independence with transfers and activities of daily living, improve sitting balance during activities of daily living, and improve hip and core strength to participate in self-care activities. Implementing FES was utilized to address these goals, in addition to improving lower extremity muscle activation, strength, and endurance.

Intervention:

During a four-week period, the patient participated in two days of physical therapy each week. The first session of the week was 45-minutes consisting of FES cycling and FES assisted activities, including sit to stand transfers, static standing, and/or supine bridging. The second session of the week was a 30-minute session consisting of non-FES activities, including bench sitting, sit to stand transfers, static standing, supine bridges, and/or cycling on an adaptive tricycle. Table 1 displays all activities completed during each session of FES and non-FES intervention treatment days each week. Slight intervention variability occurred week to week in which activities were completed due to time constants and patient preference.

Table 1: Weekly Activities Completed

Week	FES Intervention Day Activities	Non-FES Intervention Day Activities
1	FES Cycling FES assisted stand FES assisted sit to stand	Adaptive cycling Bench sit Supine bridges
2	FES Cycling FES assisted stand FES assisted sit to stand FES assisted supine bridges	Adaptive cycling Bench sit Supine bridges Sit to stand
3	FES Cycling FES assisted stand FES assisted sit to stand	Adaptive cycling Bench sit Supine bridges Sit to stand Static standing
4	FES Cycling FES assisted stand FES assisted sit to stand	Adaptive cycling Bench sit Supine bridges Sit to stand Static standing

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FES cycling was completed on a RT300 cycling machine, which allows for individuals to volitionally assist with pedaling, as well as receive motor support to aid in the cycling. During each FES cycling session, a pulse width of 150 μsec and a frequency of 40 Hz were utilized. These parameters were predetermined by the physical therapist overseeing the patient's care and based on patient specific history utilizing this intervention. Activity tolerance was monitored during each session and used as a guide for treatment time spent utilizing the RT300.

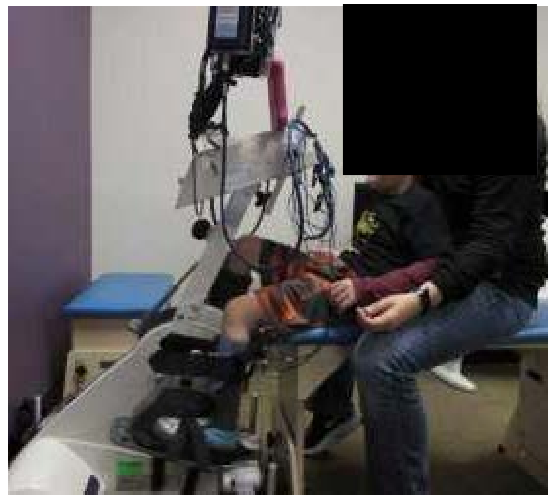

Figure 1: Patient set-up using the RT300 Cycling Machine.

Set-up when utilizing the RT300 consisted of placing two surface electrodes on each bilateral quadriceps and hamstrings over the muscle bellies (Figure 1). Palpation was utilized for placement, as well as throughout FES interventions to assess for strong motor contractions. Set-up parameters for cycling on the RT300 were as follows for each session: pulse width was 150 μsec, frequency was 40 Hz, and target speed was 30 mph. Total set-up time with the assistance of an additional therapist or rehabilitation technician for placement of electrodes and patient set-up on the RT300 was about 10 minutes. During each FES cycling session, the patient has a 1 minute warm-up and cool-down phase in which FES ramped up and down for the session. During each session, FES per muscle group was adjusted based on patient tolerance, which was reported subjectively throughout cycling. During each FES cycling session, the patient's muscle contraction was noted in his quadriceps and hamstrings with palpation. Data points were recorded on the RT300 to monitor the patient's objective values for distance traveled, average power output, average resistance, and average stimulation per session.

Following FES cycling, additional FES assisted activities were completed during this session, including sit to stand transfers, static standing, and supine bridges. Parameters for supine bridging consisted of four surface electrodes placed on bilateral gluteals and the following parameters: 26mA amplitude, pulse width of 150μsec, and frequency of 40Hz. In order for the patient to complete this activity, a ramp up and down time of three seconds was used and a five second static hold with physical assistance was utilized. To complete static standing and sit to stand transfers, two surface electrodes were placed on each bilateral quadriceps and gluteals and the following parameters were utilized: 25mA amplitude for gluteals, 30 mA amplitude for quadriceps, pulse width of 150μsec, and frequency of 40Hz. A three second ramp up and down time of was used with a 20 second on and 10 second off time ratio for static standing and sit to stand transfers. During the ramp up/down phase of this parameter the sit to stand transfer was completed. For each FES activity, varying levels of physical assistance was provided and further assessed to objectively monitor weekly progress (Figure 2). The number of

Figure 2: Image A) shows patient set-up with FES for standing and image B) shows set-up for standing without FES.

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repetitions of each activity completed was determined by the patient's activity tolerance and time constraints per each session.

Interventions completed during the non-FES sessions consisted of bench sitting, sit to stand transfers, static standing, supine bridges, and riding an adaptive tricycle with varying levels of physical assistance (Table 1). Variations of bench sitting occurred week to week consisting of use of bilateral upper extremities to play at a surface at the patient's mid-thoracic height, in addition to minimizing the use of bilateral upper extremities for additional support when completing bench sitting, sit to stand transfers, and static sitting (Figure 2). Adaptive cycling took place after functional activities were completed. Adaptive cycling took place on an adaptive tricycle with trunk support, bilateral pedal support, and adaptive steering (Figure 3). The distance traveled during each session was determined by the child's activity tolerance and time constraints per session.

Outcomes:

The patient's progress was monitored weekly throughout the four-week timeframe based on a variety of objective and subjective information documented each session. One method of tracking progress was done by evaluating the level of assistance the patient required to complete FES assisted activities and non-FES assisted activities. Additionally, data points from each RT300 session were evaluated by monitoring the average resistance, average stimulation, average power output, and distance traveled per session (Table 2).

Table 2: RT300 FES Cycling Session Outcomes

FES Session	Distance Traveled (miles)	Average Power (Watts)	Average Resistance (Nm)	Average Stimulation (μcoulomb)	Duration of Cycling (minutes: seconds)
1	1.07	0.01	0.55	4.01	11:53
2	1.09	0.03	0.54	4.00	12:04
3	1.43	0.01	0.54	4.45	15:11
4	1.29	0.07	0.56	4.45	13:00

*Pulse Width for each session: 150 μsec. Frequency for each session = 40 Hz.

During each physical therapy session, documentation was completed to show an accurate record of the type, volume, and level of assistance for each activity completed during each session. Comparisons based on the level of physical assistance needed to complete each activity were made between FES and non-FES interventions, the level of physical assistance was utilized to examine the patient's progress. Although this is a subjective means of evaluation, this method was utilized to best describe the small and large changes noted in the patient's physical function during each session. Each activity and the level of physical assistance was recorded based on the average amount of assistance provided for each activity during that session (Table 3 and Table 4). To fully capture the patient's functional abilities when riding the adaptive tricycle, the total distance traveled was recorded as well as the level of assistance required throughout cycling (Table 5).

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Discussion:

This case report discusses the use FES cycling and FES assisted activities in combination with non-FES interventions in the physical therapy treatment of a five-year-old child with spastic quadriplegic cerebral palsy over the course of four-weeks. The most significant change noted from the patient's baseline functional abilities over the course of this four-week timeframe was his improvement in his ability to volitionally pedal an adaptive tricycle. The patient progressed from maximal assistance needed to volitionally pedal and steer an adaptive tricycle, to demonstrating the ability to consistently cycle 10 feet with contact guard assist (Table 5). Additional improvements in the patient's functional abilities were noted with functional activities of bench sitting and supine bridges without FES. The patient progressed from requiring maximal assistance to complete a supine bridge to requiring minimal assistance for 60% of the session and moderate assistance for 40% of the session. Additionally, the patient progressed from requiring moderate assistance to sit on a bench to requiring minimal assistance to contact guard assistance when sitting for bouts of 3 minutes of less.

Figure 3: Patient set-up using an adaptive tricycle.

FES cycling allows children with lower levels of balance and coordination to participate in a method of physical activity that requires less balance and coordination than a traditional gym-based exercise program[11]. FES has previously been used by other CP populations to as a means to provide opportunities to children with CP to strengthen lower extremities, improve functional independence and increase physical activity participation[11]. The patient was a good candidate for utilizing FES cycling and FES aided functional activities due to history of successful utilization of the RT300 FES cycling and RT600 stepper within the past year. According the patient's current physical therapist, he had previously made gains in improving his power output with these interventions, suggesting improved bilateral lower extremity strength. The patient's family reported that his functional mobility remained relatively similar, however his physical activity level improved for home and school-related activities. Utilizing FES interventions provided a means to improve the patient's activity tolerance needed to utilize a standi frame assistive device at school to participate in age-appropriate activities in the classroom and with peers.

When utilizing the International Classification of Functioning, Disability and Health model (ICF model) and evaluating ways to increase a child's level of participation in physical activities with peers, bicycling provides a positive means to addressing this area of the ICF model. Bicycling is an age appropriate activity, that allows a child to optimize their functional mobility, work on strength gains, improve coordination, and participate in an activity that allows for children to engage with their peers. A pilot study in 2013 by Pickering et al. evaluated the impact of cycling in children with CP, to address the use of cycling as a means of adapted physical activity[12]. This study supported the use of adaptive bicycles and tricycles for children with disabilities, specifically children with CP[12]. Similar to the Pickering et al. 2013 study, adaptive tricycle riding was used as an intervention for the patient in this case report to address his lower extremity strength, endurance, and coordination deficits through an age-appropriate intervention.

The current literature is progressing in addressing the dosage and functional utilization of FES cycling and assisted interventions for children with CP[8-10,12]. A recent randomized control trial protocol by Armstrong et. al. analyzed an intervention training program of FES powered cycling, recreational cycling, and goal-directed exercise training in children with CP[11]. The aims of this protocol was to design a new and effective training program to improve physical activity, gross motor function, sit to stand transfer performance, and participation in life activities for children classified as GMFCS levels II, III, and IV[11]. Clinicians may consider utilizing a structured protocol as well as more specifically documenting the dosage of FES interventions in the pediatric population. A study by Trevisi et. al. found that pediatric patients with CP who participated in 30 minutes sessions of FES cycling three times per week were able to achieve more symmetrical muscle strategy during voluntary cycling and

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gait following a seven week bout of FES cycling intervention[8]. A case report by Johnston and Wainwright found that their participant made lower extremity strength gains and had patient reported improvements in performance and satisfaction with self-identified ICF goals[9].These studies may support that a larger timeframe may be needed to effectively assess changes after utilizing FES cycling interventions.

A limitation of this case report is the lack of utilizing standardized outcome measures during the evaluation and end of the intervention timeframe. There was difficultly in selecting an appropriate objective measure to quantify minimal changes in the patient due to limited functional abilities and age. One objective measure that has been utilized to assess gross motor function for individuals with CP is the Gross Motor Function Measure(GMFM). GMFM is an outcome measures designed to be utilized for evaluating gross motor function in children with CP age 5 months to 16 years were motor skills are delayed compared peers of the same age[4]. GMFM looks at five categories including, lying and rolling, sitting, crawling and kneeing, standing, and walking and running. GMFM-88 has been shown to be a reasonably reliable and responsive outcome measure for measuring gross motor function in children with CP[13]. Other studies evaluating the gross motor function of individuals with CP have utilized the GMFM-88 and GMFM-66 and have found benefit in utilizing these measures as they provide clinicians and families with objective information regarding the child's current gross motor function[14]. Utilizing the GMFM in this case report would have been beneficial to quantify the patient's gross motor function over the course of his multiple episodes of physical therapy care. Future clinicians should consider utilizing this measure when working with pediatric patients with CP.

An additional limitation in this case report include the short duration of sessions analyzed due to a limited data collection timeframe. Ideally, data would have been analyzed after six to eight weeks. A study by Yi et. al. examined the impact of various contributing factors for changes of gross motor function in children with spastic CP after physical therapy[15]. This study found that improvements of gross motor function through intensive physical therapy get higher if the duration of interventions is longer, there is no dysphagia, and if spasticity of the lower extremities is not severe[15]. This study found a mean improvement in GMFM-88 scores after 52 days of physical therapy[15]. This study supports that a longer duration of time may allow for further benefits to be seen following the use of FES interventions. Additionally, this case report examined the first four weeks of interventions, which may not have been too short of a timeframe for profound functional mobility changes to occur. Additionally, due to the heterogeneous nature of CP, it is difficult to compare outcomes in this case report to previous studies and case reports due to the large variance in functional abilities between individuals with CP.

When clinicians consider utilizing FES cycling and FES assisted activities as part of their treatment plans for children with CP, clinicians should consider the cost of equipment and time for set-up. In this case report, two people completed the set-up of FES activities within about 10 minutes and take-down within about 5 minutes. Based on time available for treatment sessions, additional time of 45 minutes was needed to account for set-up and take-down time when utilizing FES interventions, as compared to 30 minute sessions for non-FES interventions. If a clinician is limited on time, they may consider more traditional interventions to best utilize the patient and clinician's time to accomplish the patient and family centered goals.

This case report suggests there maybe benefits in utilizing a mixed intervention approach with FES cycling, FES assisted activities, and non-FES assisted activities in pediatric patients with spastic quadriplegic CP. Utilizing FES as an intervention for the rehabilitation of a child with gross motor deficits due to CP may provide a solution to improve muscle strength and endurance. FES cycling and adaptive cycling provide individuals with CP a means to participate in physical activity and improve activity participation in their daily lives, despite limitations in gross motor function. Physical therapist should consider utilizing FES cycling and FES assisted activities in conjunction with traditional physical therapy interventions to address patient and family specific functional goals. Future research exploring the impact of dosage and functional outcomes of utilizing FES need to be further explored.

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Table 3: FES Interventions Level of Assistance

Week	Sit to stand	Static Standing	Supine Bridge
1	ModA	ModA	X
2	ModA	ModA	MaxA
3	MaxA	ModA bouts of MinA	X
4	ModA	ModA	X

***MinA= minimal assistance (<25%), ModA = moderate assistance (50%), MaxA = maximal assistance (>75%), CGA = contract guard assistance (0%, hand placement for safety), X = activity was not completed

Table 4: Non-FES Interventions Level of Assistance

Week	Sit to stand	Static Standing	Supine Bridge	Bench Sit
1	X	X	MaxA	ModA
2	ModA use of BUE	X	ModA	MinA to ModA
3	MaxA minimal use of BUE	MaxA	MinA 50% of session ModA 50% of session	MinA
4	ModA minimal use of BUE	ModA	MinA 60% of session ModA 40%of session	MinA to CGA

***MinA= minimal assistance (<25%), ModA = moderate assistance (50%), MaxA = maximal assistance (>75%), CGA = contract guard assistance (0%, hand placement for safety), X = activity was not completed

Table 5: Adaptive Cycling Level of Assistance

Week	Total Distance (feet)	Level of Assistance
1	700	ModA with 10 bouts of CGA for 6-10 feet
2	300	ModA with 3 bouts of CGA for 6-10 feet
3	500	ModA with 5 bouts of CGA for 10 feet
4	X	X

***MinA= minimal assistance (<25%), ModA = moderate assistance (50%), MaxA = maximal assistance (>75%), CGA = contract guard assistance (0%, hand placement for safety), X = activity was not completed

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