Mapping Tools for Measuring Gross Motor Function in Conductive Education

by

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Abstract

Title: Mapping Tools for Measuring Gross Motor Function in Conductive Education

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Cerebral Palsy (CP) is a collection of disorders caused by disturbances in the developing brain before, during, or just after birth that affect the development of movement and posture resulting in limitations in activity. Two of the most widely employed gross motor function classification systems used to classify CP are the Gross Motor Function Measure (GMFM) and the Gross Motor Function Classification System (GMFCS). Despite the wide use of these classification systems, neither is fully sufficient in classifying the gross motor function of a patient with CP. A newer therapy program, Conductive Education (CE) seeks to help children with CP to develop orthofunctioning personalities. Orthofunction is the ability to respond to and solve the problems of daily living in order to live as independent of a life as possible. CE based programs typically utilize education based models which result in a wide variety of outcomes, including academic skills, social skills, communication skills, and motor function skills. This makes comparing the results of CE to traditional therapies very difficult. There is not currently a proper measure for detecting the type of motor improvements that CE aims to achieve. As a result, CE has not been proper evidence based validation. Motion capture devices could be useful in the creation of a proper measure to objectively determine improvements in function as a result of CE.

Objective improvements in gross motor function could be measured by combining the broad classification principles of the GMFCS, a modified version of the GMFM, and a motion capture device.

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Dedication

I would like to dedicate this thesis to my mother and father, Betsy and Dwayne, and my sister Tiffany King. Thank you for always supporting me!

Chapter 1
Introduction

1.1 Introduction

Cerebral Palsy (CP) is a collection of disorders caused by disturbances in the developing brain before, during, or just after birth that affect the development of movement and posture resulting in limitations in activity[1]. In the United States alone, CP has a reported prevalence of 3 to 4 per 1,000 children and is the most common cause of motor disability in childhood[2-6]. Due to its prevalence, the need for proper methods to classify the gross motor function children with CP is intuitive. However, current classification systems do not accurately depict the gross motor function abilities and functionalities of children with CP.

The Gross Motor Function Measure (GMFM) was created to be an evaluative measure with the ability to detect changes in gross motor function for children with CP[7]. The original GMFM had 85 items to test gross motor function[7]. After the need to bilaterally analyze some of the items was noted, 3 of the original items were split into items that analyzed the left and right sides individually[8]. This 88 item GMFM was called the GMFM-88. After multiple limitations of the GMFM-88 were identified, a Rasch analysis was performed, and as a result, the GMFM-66 was created[8, 9]. The GMFM-66 contains only 66 of the 88 items of the GMFM to measure gross motor function[8]. However, the GMFM-66 has an interval scale

(compared to the ordinal scale of the GMFM-88) allowing scores to be more accurately compared both within the same child and between different children[8, 9].

The Gross Motor Function Classification System (GMFCS) was created to be a standardized system for classifying the gross motor function of children with CP[10]. The GMFCS has five classification levels ranging from the least severe gross motor function impairment, Level I, to the most severe impairment, Level V[10]. Each level has descriptions for tasks that each child or youth should be able to accomplish based on their age ranging from infancy to the age of 18 years[10, 11]. The GMFCS also provides descriptions of the distinctions between each level[10, 11].

A newer form of therapy for children with CP is Conductive Education (CE). The goal of CE is to develop an orhtofunctioning personality[12]. Orthofunction is the ability to respond to and solve the problems of daily living in order to live as independent of a life as possible[12-15]. CE has not been properly validated as an effective therapy within the existing literature. This is due in part to the inability to properly compare CE to traditional, validated therapies because of its basis of educational models rather than scientific models[12, 13].

This work will analyze two of the widely used CP classification systems, the GMFM and GMFCS, and determine their limitations. Additionally, a method combining validated metrics and motion capture will be mapped to validate the effectiveness of CE.

Chapter 2
Overview of Cerebral Palsy

2.1 Progression of the Definition of Cerebral Palsy

In 1959, CP was defined as "a persisting but not unchanging disorder of movement and posture, appearing in the early years of life and due to a non-progressive disorder of the brain, the result of inference from its development" by Mac Keith and Polani[1, 16, 17]. In 1964, Bax created a new definition of CP which stated that CP is "a disorder of movement and posture due to a defect or lesion of the immature brain"[1, 16, 18]. This particular definition is often cited in the literature concerning CP[1, 16]. Bax further commented: "For practical purposes it is usual to exclude from cerebral palsy those disorders of posture and movement which are (1) of short duration, (2) due to progressive disease, or (3) due solely to mental deficiency"[1, 16, 18]. The meaning of "immature brain" was not defined in order to prevent limitations of health services[1, 16]. This definition, as with the previous definition, focused exclusively on motor deficiencies[1, 16]. In 1992, the definition of CP was again modified by Mutch, Alberman, Hagberg, Kodama, and Velickovic due to the variety of disorders that were included in CP and the advances in the knowledge of the development of infants who sustained brain damage before, during, or shortly after birth[1, 16, 19]. CP was defined as "an umbrella term covering a group of non-progressive, but often changing, motor impairment syndromes secondary to lesion or anomalies of the brain arising in the early stages of development"[1, 16, 19]. This particular definition placed focus on motor deficiencies with the acknowledgement of their varying presentation, while clearly excluding progressive diseases from being diagnosed as CP[1, 16, 19].

An International Workshops on Definition and Classification of CP was held in 2004 in order to review and if feasible, update the definition of CP[1, 16]. A revised definition of CP was proposed as a result of this workshop in 2005. The definition states: "Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder"[16]. The proposed 2005 definition specified various aspects of CP. It classified CP as a group of disorders due to the diversity of the conditions in terms of etiology, type of impairments, and severity of impairments that are considered CP[16]. The proposed 2005 definition specified that the "development of movement and posture" is altered which distinguishes CP from other disorders that present similarly to CP but are due to lesions acquired after motor abilities have been relatively well developed[16]. This proposed definition also specified that only motor disorders caused by disturbances in the brain are characterized as CP, which excludes motor disorders with solely "spinal, peripheral nerve, muscular or mechanical origins"[16]. Finally, the proposed 2005 definition specifies that other disorders or impairments may present in patients with CP, and these disorders or impairments may be caused by the same disturbance that caused CP, may be a result of secondary effects of motor impairment, or may be caused by independent factors[16]. The proposed 2005 definition was furthered modified based on reviewer and consultant input, and the new definition for CP was published in 2006[1]. The 2006 definition of CP states: "Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation,

perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems"[1]. In addition to the specifications mentioned previously for the proposed 2005 definition, the 2006 definition specifies that the disorder is permanent in order to exclude transient disorders while still recognizing that clinical manifestations may change over time and that additional clinical manifestations may develop[1].

2.2 Cerebral Palsy Prevalence

CP has been reported to have a prevalence between 1.5 and more than 4 per 1,000 live births or children within a defined range of ages based on population based studies from around the world[4, 20-24]. CP is the most common cause of motor disability in childhood[2, 4-6]. In the United States, the prevalence of CP has been reported to be about 3 to 4 per 1,000 children[2, 3].

Over the past 50 years, advancements in obstetric and neonatal care have resulted in significant declines in infant mortality especially in premature infants and infants with low birth weight in the United States and other countries[2, 25-27]. The increased neonatal survival has resulted in the increase of neurodevelopmental conditions with a major focus on CP[2, 28-30]. A population based study performed in Atlanta, Georgia found that the birth prevalence of congenital CP was 1.9 per 1,000 1-year survivors in 1985[2]. The prevalence had increased to 2.2 per 1,000 1-year survivors in 2002 with a 1.2% average annual increase[2].

2.3 Causes of Cerebral Palsy

CP is caused by a single inciting event or a discrete series of events that result in damage to the brain[1, 31]. If the brain damage occurs before or during birth, it is referred to as congenital CP[31]. The majority of CP cases, between 85 and 95%, are

congenital[31]. Ischemic stroke, which is when a blood vessel in the brain is blocked by a blood clot, causes brain damage that can result in CP and may occur in the developing brain during pregnancy or just after birth[4]. Hypoxia, or the disruption of the oxygen supply, during birth, is another cause of CP[4]. However, it is only estimated to cause 6% of CP[4, 32]. If the brain damage occurs more than 28 days after birth, it is referred to as acquired CP[31]. Acquired CP is typically associated with a head injury or infection such as meningitis or encephalitis[31].

2.4 Cerebral Palsy Types

The core feature of CP is abnormal motor behavior that is characterized by abnormal gross and fine motor function and abnormal posture related to defective coordination of movements or regulation of muscle tone[1, 16]. Motor impairments associated with CP begin to present within the first 18 months of a child's life in the form of delayed or atypical motor progress[16]. However, many children require medical attention for neonatal problems before impairments in gross motor function present and a diagnosis of CP is given[16]. Once a diagnosis of CP is given, children may be sorted into one of the 3 main types of CP based on the presentation of their motor impairments. If a child with CP presents motor impairments that fall into multiple types of CP, then the child should be classified as the type whose features are more dominantly presented[33].

Spastic CP is the most common form of CP affecting between 70 and 80% of people with CP and is caused by damage in the motor cortex [34-37]. Spasticity is the result of damage to the corticospinal tracts and corticobulbar tracts[35]. Spastic CP is characterized by having hypertonia (increased muscle tone) and pathological reflexes[33, 35]. The pathological reflexes will either be in the form of hyper-reflexia (increased reflexes) or pyramidal signs[33]. Hypertonia causes the muscles to feel

stiff[34, 35]. Hyper-reflexia is often associated with involuntary, rhythmic muscle contractions[33]. Spastic CP is typically described in terms of the parts of the body that are affected[34]. Spastic diplegia mainly affects the legs and may affect the arms to a less extent[34, 36, 37]. Spastic hemiplegia only affects the arm and leg of one side of the body and the arm is typically more affected than the leg[34, 36, 37]. Spastic quadriplegia affects the legs and arms, and it may also affect the trunk, face, and mouth[34, 36, 37]. Spastic quadriplegia is the most severe form of spastic CP[34, 36, 37].

Dyskinetic CP only affects about 6% of people with CP and results from damage to the basal ganglia[36, 38]. Dyskinetic CP is characterized by involuntary and uncontrollable movements of hands, arms, feet, and legs with variable muscle tone[33, 34, 36-38]. There are 3 subtypes of dyskinetic CP: dystonic CP, athetotic CP, and choreo-athetotic CP. Dystonic CP is characterized by involuntary muscle contractions resulting in slow twisting or repetitive movements and abnormal postures[33, 38]. Focal dystonia is localized to one part of the body, while generalized dystonia affects the entire body[38]. Athetotic CP is characterized by continuous, involuntary, slower writhing or contorting movements that may be worsened by attempts to move[33, 38]. Choreo-athetotic CP is characterized by a combination of chorea and athetosis movements[33, 38]. Chorea has involuntary movements that are rapid, irregular, jerky, and unpredictable[33, 38].

Ataxic CP is the least common form of CP only affecting about 6% of people with CP and results from damage to the cerebellum[36, 39]. Ataxic CP is characterized by lack of coordination in voluntary movements resulting in movements with abnormal rhythm, abnormal accuracy, and abnormal force[33, 34, 37, 39]. Tremors, hypotonia (decreased muscle tone), over or undershooting targets for goal directed movements, and lack of balance are other features of ataxic CP[33, 34, 37, 39]. Ataxia can affect

any part of the body including the legs, arms, hands, fingers, eyes, and muscles used for speech and swallowing[39]. People with ataxic CP tend to walk with a wide-based gait to attempt to compensate for their lack of balance and instability[34, 37, 39]. They also have difficulty with fine motor tasks such as writing that require quick movements and proper motor control [34, 37, 39].

Chapter 3
The Gross Motor Function Measure

3.1 Creation of the Original Gross Motor Function Measure

The Gross Motor Function Measure (GMFM) was originally created with the intent of creating an evaluative measure with the ability to detect changes in gross motor function for children with CP[7]. It was designed to assess the motor function of a child in a quantitative manner without assessing the quality of the motor function[7]. As such, it is probable that the GMFM only partly reflects changes in motor function as many times improvement in areas of motor function is only in the quality of movement rather than the quantity[7].

The original GMFM had 85 items and was created by taking items from the Motor Control Assessment of Steel and Spasoff and from Hoskins and Squires[7, 40, 41]. Each of these items were chosen for their ability to demonstrate a change in function[7]. Additionally, a 5 year old child with normal motor function should be able to accomplish each of the items without difficulty[7]. Each of the items of the GMFM were grouped into five categories of gross motor function[7]. Prone and supine positions are represented by items in the lying and rolling dimension, while four-point and kneeling positions are represented by items in the crawling and kneeling dimension[7]. Sitting and standing were given their own dimensions, while walking, running, and climbing stairs are represented by the items in the walking, running, and jumping dimension[7]. Each task is scored on a four-point Likert scale in which a score of 0 indicates that the child was unable to perform the task, a score of 1 indicates that the child was able to initiate the task but unable to complete 10% or more of the task, a score of 2 indicates that the child was able to complete between

10% and less than 100% of the task, and a score of 3 indicates that the child was able to complete the task successfully[7]. Each of the five dimensions are weighted equally in the total GMFM score[7]. The total score for each dimension is tabulated as a percentage, and then the percentages for each dimension are combined and divided by 5 to obtain the total score as a percentage[7]. A goal total score is also calculated from only the dimensions identified as goal areas by the therapist[7]. It was of importance to determine whether or not the child was completing each task independently, or if they were using the assistance of assistive devices or with active physical assistance from another person[7]. The design of the GMFM allows therapists to administer the test first without any assistive devices and then subsequently administer the test again with the use of assistive devices. The results could then be compared to determine if the assistive device is improving gross motor function.

During the pilot study to create the GMFM, children with CP, children with acute head injuries, and children without disabilities were used in the study group[7]. After completing the study, the children were split into groups depending on how both the therapists and parents viewed their change in motor function[7]. Children whose motor function was determined to have had no change or to have only slightly changed by both the parents and therapists were classified as stable[7]. Children whose motor function was determined to be improved by both the therapists and parents were classified as responsive[7]. It appears that children whose parents and therapists could not agree whether or not a change had occurred and children who showed a decrease in function were removed from further analysis. The stable group did not show a significant difference between GMFM scores throughout the study, while the responsive group did show a significant difference in GMFM scores throughout the study[7].

Each therapist was properly trained to use the GMFM prior to the study in order to reduce intra-observer variance[7]. The intra-rater reliability of the GMFM was studied by having the therapists administer and score the GMFM on the child twice over a two-week period[7]. This amount of time was chosen because no change in motor function is expected over this short of a duration[7]. The intra-rater reliability was calculated for each dimension of the GMFM as well as the entirety of the GMFM, and each dimension and the whole of the GMFM were found to have an intra-class correlation value of 0.99 with the exception of the standing dimension which had an intra-class correlation of 0.92[7]. This confirmed that the GMFM is reliable within the same observer[7].

The inter-rater reliability of the GMFM was studied by having 11 therapists score the same child during the same session[7]. The inter-rater reliability was calculated for each of the GMFM dimensions and the entirety of the GMFM[7]. The lying and rolling dimension had an inter-rater intra-class correlation of 0.87[7]. The sitting dimension had an inter-rater intra-class correlation of 0.92[7]. The crawling and kneeling dimension had an inter-rater intra-class correlation of 0.98[7]. The remaining two dimensions (standing and walking, running, and jumping) as well as the entirety of the GMFM had an inter-rater intra-class correlation of 0.99[7]. This confirmed that the GMFM is reliable between different observers[7].

3.2 Creation of the GMFM-88

After the GMFM was initially validated, feedback from clinicians involved with the validation study prompted the addition of 3 items to the GMFM[8]. The original GMFM items 41, 59, and 63 were split into two items in order to assess them bilaterally[7, 8]. Based on the current GMFM-88 score sheet, the original item 41 ("Four point position from sitting on floor") was split into items 31 ("sit on mat with

feet in front: attains 4 point over R side") and 32("sit on mat with feet in front: attains 4 point over L side")[7, 42]. The original item 59 ("stands from high kneel") was split into items 60 ("high kn: attains std through half kn on R knee, without using arms") and 61 (high kn: attains std through half kn on L knee, without using arms")[7, 42]. The original item 63 ("cruises, 2 hands on rail (5 steps each way)") was split into items 65 ("std, 2 hands on large bench: cruises 5 steps to R") and 66 ("std, 2 hands on large bench: cruises 5 steps to L")[7, 42]. This 88 item GMFM became known as the GMFM-88.

3.3 Identifying and Correcting Limitations of the GMFM-88

Further use of the GMFM-88 began to demonstrate limitations within the measure. Some users began to only study the dimensions that were relevant to their clients' level of function in order to increase the responsiveness of the measure by eliminating irrelevant items that were highly unlikely to change as a result of therapy[8]. Despite the increase of responsiveness, it has been shown that the GMFM-88 is more reliable and valid when the whole of the measure is used[7]. Another limitation that came to light was the interpretation of the total score[8]. Children who had different abilities and skills within one dimension and between different dimensions could receive the same total score due to the equal weighting of the dimensions in the total score[8]. Lastly, children who initially had mid-scale functionality had a much greater probability of a change in GMFM-88 scores over time than those children who had very low or very high functionality due to the increased number of items in the middle of the scale compared to those at the extremes of the scale[8].

To correct the limitations of the GMFM-88, the Rasch partial credit model of item analysis was applied to the GMFM-88[8, 9]. There were several reasons for choosing

to apply Rasch scaling to the GMFM-88. Rasch scaling allows the items to be arranged in order of difficulty, or hierarchically[8, 9]. Rasch scaling also allows for interval scales to be created from ordinal scales because the resulting scores take into account the difference in difficulty between items[8, 9]. The interval scaling allows for better interpretation of scores, for determining the amount of change when comparing current scores to previous scores, and for direct comparison between children with different functional abilities[8, 9]. The Rasch analysis eliminates "items that do not fit the unidimensional construct", in this case, gross motor ability[8, 9]. This allows for sample-free calibration, which allows the measure "to produce stable item estimates regardless of the sample of subjects used to calibrate the items"[9]. Lastly, Rasch analysis allows for a total score to be calculated without all items of the test being administered[8, 9]. This allows for test-free measurements, which allows the expected score to be independent of which items were tested[9].

Firstly, the items from the GMFM-88 that would comprise the unidimensional set required by the Rasch model had to be identified[9]. It was important that the unidimensional set of items meet the assumptions required by the Rasch model, maintain the measure's ability to detect changes in motor function over time, span all of the abilities commonly witnessed in patients with CP, and be clinically meaningful items[9]. The Rasch modeling helped identify 66 of the 88 items on the GMFM-88 that would form a unidimensional hierarchical scale[8]. This 66 item GMFM became known as the GMFM-66.

One major downside of utilizing Rasch analysis was that in order to score the newly created measure, a computer program would be required. As such the Gross Motor Ability Estimator (GMAE) was created for this purpose[9]. The scoring algorithm was developed in order to assign the best fitting estimate of ability while allowing for missing data[9]. An important change from the GMFM-88 scoring is the importance

of noting whether an item was not tested or if the child was unable to perform to task (and therefore received a true score of 0)[8]. As such the GMFM-66 score sheet contains a place to mark items that were not tested[8, 42]. Simulations of hypothetical children that fit the Rasch model were ran to find the minimum number of items that needed to be tested in order to have a sufficiently accurate ability estimate[9]. It was found that on average only 13 items were needed for accurate ability estimation[9]. However, it should be noted that the accuracy of the resulting estimate of motor ability is directly correlated to the number of items tested[8, 9]. The items of the GMFM-66 were split alternately into 2 groups and motor ability estimates were determined using each group of items for each child[9]. The intra-correlation coefficient for the estimates calculated for each group was 0.98. This along with the simulations to determine the minimum number of items required for an accurate result, indicated that the GMFM-66 was providing test-free measurements[9].

The GMAE computes the GMFM-66 score and plots that score on an item map with 95% confidence intervals[9]. The GMAE also provides the ability to track the progress of a child over time[9]. The GMFM-66, using the GMAE scoring method, had an intra-class correlation for test-retest reliability 0.9932, which was not significantly different from the GMFM-88's intra-class correlation of 0.9944. [8]. Therefore it was determined that the GMFM-66 was reliable[8].

One reason that the Rasch partial credit model was chosen was because the model does not assume the relative difficulty of the steps within the items or the response options[9]. The sample size was believed to be large enough in order to calculate reliable estimates of each item's difficulty[9]. The difficulty of receiving a score of 3 for each item of the GMFM-66 was determined using the Rasch analysis[8, 9]. The difficulties were transformed into a scale with values ranging from 0 to 100[8, 9]. The easiest item, item 21 ("sit on mat, supported at thorax by therapist: lifts head upright,

maintains 3 seconds") had a difficulty estimate of 15.72, while the most difficult item, item 82 ("std on R foot: hops on R foot 10 times within a 60 cm (24") circle") had a difficulty estimate of 88.52[8, 42]. This was an expected result as one would assume that items from the lying and rolling dimension would be easier to perform than items in the standing or walking, running, and jumping dimensions[8]. Additionally, the reliability of the difficulty estimates was also studied[9]. It was found that the intra-correlation coefficients were all greater than 0.96 for stability over time, stability between random samples, and stability between samples that had been intentionally biased in terms of motor function ability[9]. These results concluded that the GMFM-66 was providing sample-free measurements[9].

Before the GMFM-66 was validated, the Gross Motor Function Classification System (GMFCS), which is described in the next chapter, was created. This classification system was used to further divide the sample used for validation of the GMFM-66. Mean ability estimates were calculated for children within each GMFCS level[8]. Children classified as GMFCS Levels I, II, III, IV, and V were found to have mean ability estimates of 78.06, 60.92, 49.98, 37.94, and 20.63, respectively[8]. The mean score for all children of the first GMFM-66 test was 52.76, and the final mean score for all children was 54.61[8]. This overall change demonstrated that the GMFM-66 is responsive[8]. The results demonstrated that children below the age of 5 years will have a greater change in GMFM-66 scores than children aged 5 years or older[8]. Additionally, the results showed that children classified in GMFCS Levels I and II (i.e. the levels with the highest motor function) had greater changes than those classified in the other GMFCS levels[8]. Lastly, the results showed a mean GMFM-66 score change of zero for children, regardless of GMFCS level, aged 5 years or older[8].

3.4 Limitations of the GMFM-88 and GMFM-66

While the GMFM-88 and GMFM-88 are adequate in assigning a value to motor function ability, that value, especially in the case of the GMFM-88, does not clearly indicate what motor function abilities the child possesses. For example, a child with hemiplegia could receive a similar score in the lying and rolling dimension of GMFM-88 as a child with lower functional mobility due to the inability to fully complete tasks designed to test one side of the body. Since the GMFM-88 weights all dimensions equally in its total score, the child could also have a similar total GMFM-88 score to that of a child without hemiplegia who has a lower degree of motor ability. This classification system lacks any assessment of upper body movement as well as the assessment of the quality of movement performed. The classification system also lacks clarity with respect to determining specifically what qualifies as a score of 1 (i.e. the child initiates movement but completes less than 10% of the task), 2 (i.e. the child partially completes the task by performing more than 10% but less than 100% of the task), or 3 (i.e. the child completes the task)[7]. Although determining completion of a task may be intuitive for certain items of the GMFM-66 and GMFM-88, other tasks are not. For example, item 63 of both the GMFM-88 and GMFM-66 tests the child's ability to move into a squat position with the arms free[42]. The angle of the knee that constitutes a squatting position is not described. Therefore, the therapist administering the test must determine subjectively if the squat position is fully reached or if only a percentage of the squat is achieved. Even for tasks such as item 69, which tests the ability of the child to walk forward 10 steps, that are easier to determine completion do not have clear guidelines[42]. For example, if a child attempted to initiate movement but stumbled and inadvertently was able to complete a single step, should that child be given a score of 1 or 2? Arguments could be made for both scores. The child clearly was not fully able to take a single step and could therefore be

scored as a 1 due to the initiation of the task. However, a single step would account for 10% of the task's completion signifying that the child should receive a score of 2. If the child was given a score of 2 for this task, this child would, according to the result, have equivalent functional ability for this task as another child who could only complete 9 steps. This example demonstrates the importance for more specific guidelines for the scoring of each item.

Chapter 4
The Gross Motor Function Classification System

4.1 Overview of the Gross Motor Function Classification System

The Gross Motor Function Classification System (GMFCS) was first presented in 1997[10]. The aim of the original proposed classification system was to create a standardized system in order "to classify the gross motor function of children with cerebral palsy"[10]. Prior to the GMFCS, patients with CP were sorted into the categories of mild, moderate, or severe cerebral palsy. However, these categories did not have specific guidelines for each disability level as evidenced by the wide ranges of GMFM scores for children at different ages in each classification. Some of the GMFM scores for children classified in the same category had scores ranges varying more than 20% for children of the same age in months. The GMFCS has five classification levels ranging from the least severe gross motor function impairment, Level I, to the most severe impairment, Level V[10]. Each level has its own description for tasks that each child should be able to accomplish based on their age. The GMFCS originally had descriptions of the self-initiated movements that the child should be able to perform for each level divided into children under the age of 2, children aged 2 to 4 years, children aged 4 to 6 years, and children aged 6 to 12 years (with the exception of Level V which only had divisions of children under the age of 2 and children aged 2 to 12 years)[10]. In 2007, the GMFCS-Expanded and Revised (GMFCS-E&R) was developed which created an additional age bracket from 12 to 18 years for all levels and split the 2 to 12 year bracket for Level V to match the age brackets of the other levels[11]. The GMFCS also has descriptions of the distinctions between each level[10, 11].

4.2 The GMFCS

GMFCS Level I generally entails that a child walks without any limitations but has limitations in more difficult gross motor skills[10, 11]. For a child under the age of 2 years to be classified as Level I, the child should be able to move into and out of a sitting position and be able to sit on the floor with both hands free[10, 11]. The child should also be able to crawl on hands and knees as well as be able to pull up to a standing position and be able to take steps while holding onto a piece of furniture[10, 11]. The child should be able to walk without the need of an assistive device between the ages of 18 months and 2 years[10, 11]. For a child between the ages of 2 and 4 years to be classified as Level I, the child should be able to sit on the floor with both hands free as well as be able to move into and out of a sitting or standing position without assistance from an adult[10, 11]. Children at this age should also walk without assistive devices as the preferred mobility method[10, 11]. For a child between the ages of 4 and 6 years to be classified as Level I, the child should have the ability to get into, get out of, and sit in a chair without support from the hands[10, 11]. The child should also be able to move into and out of a sitting or standing position without assistance from nearby objects[10, 11]. The child should be walking both indoors and outdoors, climbing stairs, and should begin to have the ability to run and jump[10, 11]. For a child between the ages of 6 and 12 years to be classified as Level I, the child should be able to walk up and down curbs without assistance and climb stairs without the assistance of the railing[10, 11]. The child should be walking in home, school, outdoor, and community environments, and the child may participate in sports and other physical activities[10, 11]. The child should be running and jumping, albeit with limited speed, balance, and coordination[10, 11]. For a youth between the ages of 12 and 18 years to be classified as Level I, the youth should be able to perform all of the same gross motor skills as those stated for children aged 6 to 12 years[11].

GMFCS Level II generally entails that a child walks without assistive devices but walks with limitations in outdoor and community settings[10, 11]. For a child under the age of 2 years to be classified as Level II, the child should be able to maintain a sitting position on the floor with the aid of the hands for support and in order to maintain balance[10, 11]. The child should be able to creep on his or her stomach or crawl on hands and knees, and the child might have the ability to pull into a standing position or to take steps while holding on to furniture[10, 11]. For a child between the ages of 2 and 4 years to be classified as Level II, the child should be able to maintain a sitting position on the floor but may have difficulty balancing when sitting with both hands free[10, 11]. The child should be able to move into and out of a sitting position without assistance from an adult[10, 11]. The child should also be able to pull into a standing position on stable surfaces, to crawl reciprocally on hands and knees, to "cruise holding onto furniture", and to walk with the aid of an assistive device as the preferred mobility method[10, 11]. For a child between the ages of 4 and 6 years to be classified as Level II, the child must be able maintain a sitting position in a chair with the hands free and be able to move from floor sitting and chair sitting into a standing position with the assistance of a stable surface to pull or push up on with the arms[10, 11]. The child should be able to walk without hand-held mobility devices in indoor environments or over short distances on level surfaces in outdoor environments and be able to climb stairs with the assistance of a hand railing [10, 11]. However, the child does not have the ability to run or jump[10, 11]. For a child between the ages of 6 and 12 years to be classified as Level II, the child should be able to walk in most environments but may have trouble walking over longer distances and maintaining balance on uneven or inclined surfaces, in crowed areas, in confined spaces, or when carrying items[10, 11]. The child should be able to walk up and down stairs with the assistance of a hand railing or in the absence of a railing, with the assistance of another person[10, 11]. The child should be able to walk with the assistance of another person

or a hand-held mobility device in outdoor or community environments[10, 11]. However, the child may utilize a wheeled mobility device when traversing longer distances[10, 11]. The child may have a minimal ability to run and jump, and as such, the child may require adaptations to participate in sports and other physical activities[10, 11]. For a youth between the ages of 12 and 18 years to be classified as Level II, the youth should be able to walk in most environments but the preferred mobility method may be altered depending on factors such as uneven surfaces, inclines, longer distances, weather, or personal preference[11]. The youth may utilize wheeled mobility when traveling long distances in outdoor or community settings[11]. The youth should walk with the assistance of hand-held mobility devices to increase safety in school or work settings[11]. The youth should be able to walk up and down stairs with the assistance of a hand railing or in the absence of a railing, with the assistance of another person[11]. Limitations in the youth's gross motor abilities may require that the youth use adaptations to participate in sports and other physical activities[11].

GMFCS Level III generally entails that a child is able to walk using a hand-held assistive mobility device such as canes or crutches, and that a child has limitations walking in outdoor or community settings[10, 11]. For a child under the age of 2 years to be classified as Level III, the child should be able to maintain a sitting position on the floor with the lower back supported, and the child should be able to creep on his or her stomach and roll[10, 11]. For a child between the ages of 2 and 4 years to be classified as Level III, the child should be able to maintain a sitting position (this may often be the "W-sitting" position) on the floor but may need the assistance of an adult to get into the sitting position[10, 11]. The child should be able to crawl non-reciprocally on hands and knees or creep on his or her stomach as the primary method of self-mobility[10, 11]. The child might be able to pull up into a standing position on

stable surface, be able to "cruise short distances", or be able to walk indoors over short distances with the assistance of a hand-held mobility device and adult assistance for turning[10, 11]. For a child between the ages of 4 and 6 years to be classified as Level III, the child should be able to maintain a sitting position on a normal chair albeit with pelvic or trunk support in order to maximize the function of the hands[10, 11]. The child should be able to move into and out of a sitting position in a chair with the assistance of a stable surface to pull or push up on with the arms[10, 11]. The child should have the ability to walk with the assistance of hand-held mobility devices and to climb stairs with the assistance of an adult[10, 11]. The child is usually transported over long distances or in outdoor environments with uneven surfaces[10, 11]. For a child between the ages of 6 and 12 years to be classified as Level III, the child should be able to walk in most indoor environments using hand-held mobility devices[10, 11]. The child may require a seat belt when in a sitting position to aid in balance and pelvic alignment[10, 11]. The child requires the assistance of another person or a surface to provide support to move from a sitting to standing position and to move from a position on the floor to a standing position[10, 11]. The child uses wheeled mobility when traversing long distances[10, 11]. The child may have the ability to walk up and down stairs with the assistance of a hand railing or in the absence of a railing, with the assistance of another person[10, 11]. Limitations in the child's walking ability may require that the youth use adaptations, including manual or powered wheeled mobility, to participate in sports and other physical activities[10, 11]. In order for a youth between the ages of 12 and 18 years to be classified as Level III, the youth should have the ability to walk using a hand-held mobility device and may have more variability in the preferred mobility method depending on environmental factors and personal preferences[11]. The youth may require a seat belt when in a sitting position to aid in balance and pelvic alignment[11]. The youth requires the assistance of another person or a surface to provide support to move from a sitting to

standing position and to move from a position on the floor to a standing position[11]. In school settings, the youth may utilize a manual wheelchair or powered mobility device, and in outdoor and community environments, the youth is transported via a wheelchair or powered mobility device[11]. The youth may have the ability to walk up and down stairs with the assistance of a hand railing or in the absence of a railing, with the assistance of another person[11]. Limitations in the youth's walking ability may require that the youth use adaptations, including manual or powered wheeled mobility, to participate in sports and other physical activities[11].

GMFCS Level IV generally entails that a child is able to have self-mobility with limitations, and that a child may be either transported or utilize a powered mobility device in outdoor and community settings[10, 11]. For a child under the age of 2 years to be classified as Level IV, the child should be able to roll into a supine position and may be able to roll into prone position[10, 11]. The child may also have control of their head, but the child requires proper trunk support in order to sit on the floor[10, 11]. For a child between the ages of 2 and 4 years to be classified as Level IV, the child should be able to sit when place on the floor but do not have the ability to maintain balance or alignment without the assistance of the hands[10, 11]. The child very often requires adaptive equipment for sitting and standing[10, 11]. However, the child should be able to achieve self-mobility within a room via rolling, creeping on his or her stomach, or crawling non-reciprocally on hands and knees[10, 11]. For a child between the ages of 4 and 6 years to be classified as Level IV, the child should have the ability to sit on a chair with adaptive seating to facilitate control of the trunk and to maximize the function of the hands[10, 11]. The child is able to move into and out of a sitting position on a chair either with the assistance of an adult or the assistance of a stable surface to pull or push up on with the arms[10, 11]. The child may have the ability walk with a walker and adult supervision over short

distances but has trouble "turning and maintaining balance on uneven surfaces"[10, 11]. The child is always transported within community settings but may attain self-mobility via a powered wheelchair[10, 11]. For a child between the ages of 6 and 12 years to be classified as Level IV, the child should be utilizing powered mobility devices or mobility methods that require the assistance of another person in most environments[10, 11]. The child requires adaptive seating to facilitate control of the trunk and pelvis[10, 11]. The child requires assistance from another person for most transfers[10, 11]. In the home, the child may utilize floor mobility such as rolling, creeping, crawling, may walk with assistance from another person over short distances, or may utilize powered mobility devices[10, 11]. In home or school environments, the child may utilize a body support walker[10, 11]. The child is always transported via manual wheelchair or powered mobility devices within community, school, and outdoor environments[10, 11]. Limitations in the child's mobility require that the child use adaptations, including powered wheeled mobility or the assistance of another person, to participate in sports and other physical activities[10, 11]. For a youth between the ages of 6 and 12 years to be classified as Level IV, the youth should be using wheeled mobility in most environments[11]. The youth requires adaptive seating to facilitate control of the trunk and pelvis[11]. The youth requires the assistance of one or two others during transfers, but the youth may be able to support their own weight via the legs in order to assist with standing transfers[11]. In indoor environments, the youth may be able to walk for short distances with the assistance of another person, a body support walker, or wheeled mobility devices[11]. The youth should have the physical capabilities to operate a powered wheelchair[11]. However, when a powered wheelchair is not available, the youth is transported via a manual wheelchair[11]. Limitations in the youth's mobility require that the child use adaptations, including powered wheeled mobility or the assistance of another person, to participate in sports and other physical activities[11].

GMFCS Level V generally entails that a child has severely limited self-mobility even with the aid of assistive devices, and that the child is transported in all settings[10, 11]. For a child under the age of 2 years to be classified as Level V, the child must be very limited in voluntary movement control due to physical impairments and must be unable to roll without the assistance of an adult[10, 11]. The child is also "unable to maintain antigravity head and trunk postures in prone or sitting" positions[10, 11]. For child between the ages of 2 and 4 years to be classified as Level V, the child must have physical impairments which restrict voluntary movement control and the ability "to maintain antigravity head and trunk postures"[10, 11]. The child has limited motor function in all aspects, and adaptive equipment and assistive technologies do not fully compensate for the child's limitations in sitting and standing[10, 11]. The child is unable to move independently and is always transported[10, 11]. However, the child may attain self-mobility via the use of a heavily adapted powered wheelchair[10, 11]. For a child between the ages of 4 and 6 years to be classified as Level V, the child must have physical impairments which restrict voluntary movement control and the ability "to maintain antigravity head and trunk postures"[10, 11]. The child has limited motor function in all aspects, and adaptive equipment and assistive technologies do not fully compensate for the child's limitations in sitting and standing[10, 11]. The child is unable to move independently and is always transported, but some children may attain self-mobility via the use of a heavily adapted powered wheelchair[10, 11]. In order for a child between the ages of 6 and 12 years to be classified as Level V, the child should be transported via a manual wheelchair in all environments, and the child must be "limited in their ability to maintain antigravity head and trunk postures and control arm and leg movements"[10, 11]. Adaptive equipment and assistive technologies do not fully compensate for the child's limitations in head alignment, sitting, standing, or mobility[10, 11]. The child requires complete physical assistance from another person to complete transfers[10, 11]. In the home, the child may have

to ability to move for short distances on the floor, or the child may be carried by an adult[10, 11]. The child may be able to achieve self-mobility via extensively adapted powered mobility devices[10, 11]. Limitations in the child's mobility require that the child use adaptations, including powered wheeled mobility or the assistance of another person, to participate in sports and other physical activities[10, 11]. In order for youth between the ages of 12 and 18 years to be classified as Level V, the youth meet all of the same requirements as those listed for children aged 6 to 12 years with the addition that transfers require the assistance of one or two others or the assistance of a mechanical lift to complete[11].

Table 1. Descriptions of Function for Children Between the Ages of 6 and 12 Years for Each GMFCS Level[10, 11]

GMFCS Level	Description of Function for Level
Level I	• Children walk in home, school, outdoor, and community environments. • Children can climb stairs without the aid of a hand railing. • Children can run and jump, but have limited speed, balance, and coordination.
Level II	• Children walk in most environments. • Children may climb stairs with the assistance of a hand railing.

	• Children may have difficulty walking and balancing in environments with uneven terrain, inclines, crowded areas, or confined spaces. • Children may walk with assistance from another person or a hand-held mobility device or utilize wheeled mobility over long distances. • Children may have minimal ability to run and jump.
Level III	• Children walk with the assistance of a hand-held mobility device in most indoor environments. • Children may climb stairs with the assistance of a hand railing or of another person. • Children utilize wheeled mobility over long distances. • Children may use self-propelled mobility over shorter distances.
Level IV	• Children utilize powered mobility devices or mobility methods requiring assistance from another person in most environments. • Children may walk for short distances in home environments with assistance from another person or a body support walker

	or utilize powered mobility devices. • Children are transported in school, outdoor, and community environments via a manual wheelchair or powered mobility device.
Level V	• Children are transported in all environments via a manual wheelchair. • Children have limited ability to maintain antigravity head and trunk postures. • Children have limited ability to control movements of the arms and legs.

4.3 Distinctions Between GMFCS Levels

In order to improve accuracy of the GMFCS-E&R, a list of distinctions between each level are provided. The distinctions between Levels I and II are that, compared with those in Level I, children and youth in Level II may have limitations in balancing and in walking for long distances, may require the use of hand-held mobility devices when learning to walk, may utilize wheeled mobility devices in outdoor and community environments, may require hand railings to walk up and down stairs, and may not be as capable of running and jumping[10, 11]. The distinction between Levels II and III is that children and youth classified as Level II do not require a hand-held mobility devices for walking after the age of 4 years (except for instances when they choose to utilize them) while children and youth classified as Level III require hand-held

mobility devices to walk in indoor environments and may utilize wheeled mobility devices in outdoor and community environments[10, 11]. The distinctions between Levels III and IV are that children and youth classified as Level III have the ability to sit without support (or at most require limited external support), have more independence during standing transfers, and have the ability to walk with hand-held mobility devices while children and youth classified as Level IV have the ability to sit but are usually supported, have limited self-mobility, and have a higher likelihood of being transported via manual wheelchairs or a powered mobility devices[10, 11]. The distinctions between Levels IV and V are that children and youth classified as Level V have "severe limitations in head and trunk control", require extensive assistive technologies and physical assistance from another person, and may only achieve self-mobility via learning how to operate powered wheelchairs[10, 11].

4.4 Reliability and Stability of the GMFCS

During the pilot study to create the GMFCS, the therapists involved in assigning classifications to the children were given no special training, and they "were not required to perform any assessment procedures"[10]. Since each child was evaluated by at least two therapists who had known them for at least 3 months, inter-rater reliability was able to be evaluated[10]. It was found that for children under 2 years of age, if a therapist concluded that the child fell into Level I then there was an 88% probability that the other therapists would classify that same child into the same level[10]. While the probability of other therapists classifying the same child in the same level decreased as the level increased for children under 2 years of age, it was found that there was still a 44% probability that if one therapist classified a child as Level V, then the other therapists would as well[10]. For children aged between 2 and 12 years of age, the probabilities associated with inter-rater same level classification were slightly different. If one therapist classified a child as Level I there was only a

67% chance that the other therapists would also classify that child as Level I[10]. Level II classifications had the lowest reliability with only 55% probability of being classified as the same level[10]. However, Levels III, IV, and V showed 92%, 87%, and 89% inter-rater same level classifications[10]. Since the goal of the GMFCS was to be a standardized classification system, the GMFCS has been repeatedly tested for overall inter-rater reliability. In the pilot paper published in 1997, the overall inter-rater reliability was reported to be a chance-corrected agreement of 0.75[10]. In 2000, Wood and Rosenbaum tested the overall inter-rater reliability and found a generalizability coefficient value of 0.93[43].

The reliability and stability of the GMFCS has also been studied. Reliability determines the ability of the GMFCS level to remain constant between raters and over time, while stability determines the ability of the GMFCS level to remain constant over time. Wood and Rosenbaum found that the overall test-retest reliability had a generalizability coefficient of 0.79, meaning that in general a child will maintain the same level classification from the age of 1 to 2 years to the age of 6 to 12 years[43]. However, in the same study test-retest reliability was examined between different time periods[43]. Test-retest reliability from ages 1 to 2 to ages 6 to 12, from ages 2 to 4 to ages 6 to 12, and from ages 4 to 6 to ages 6 to 12 had generalizability coefficients of 0.68, 0.82, and 0.87, respectively[43].

4.5 Predictability of Walking Based on GMFCS Level

Parents are constantly wondering if their child will ever have the ability to walk. Unfortunately for researchers, parents, and patients alike, the term "walking" is not dichotomous in terms of determining the ability of a patient with CP. Level III of the GMFCS specifies the ability of children aged 6 to 12 years to walk indoors or outdoors on a level surface with the assistance of a mobility device[10]. When assisted

walking is classified as having the ability to walk, it was found that a child classified as Level I, II, or III between the ages of 1 and 2 years had a positive predictive value of the ability to walk of 0.74 and a negative predictive value (meaning that the child would rely solely on wheeled mobility) of 0.77[43]. If the child was classified as Level I, II, or III between the ages of 2 and 4 years or between the ages of 4 and 6 years, the positive predictive values were 0.87 and 0.91, respectively[43]. However, if assisted walking is not considered having the ability to walk and therefore Level III patients are lumped in with Levels IV and V, then children classified at these levels between the ages of 1 and 2 years only have a positive predictive value of 0.57 and a negative predictive value of 0.90[43]. Furthermore, if the child was classified as Level III, IV, or V between the ages of 2 and 4 years or between the ages of 4 and 6 years, the positive predictive values were 0.62 and 0.80, respectively[43].

4.6 Development of Gross Motor Function Curves

Gross motor function curves have been developed to further define the relationship between age and gross motor function for each level of the GMFCS in terms of GMFM scores. Initially, the motor function curves were developed in terms of the GMFM-88, as the GMFM-66 was not in use yet. Palisano et al. tested multiple mathematical models in order to generate best fit curves of the data, and it was found that a model which assumed that children with different GMFCS levels differed "in both their limit of gross motor function" and the rate at which that limit was approached most accurately depicted the data[44]. This model was "able to explain 83% of the variation associated with GMFM scores"[44]. The predicted maximum GMFM-88 score was shown to be higher for each successively higher functional GMFCS level[44]. The predicted maximum GMFM-88 scores for Levels I, II, III, IV and V were found to be 96.8, 89.3, 61.3, 36.1, and 12.9, respectively[44]. Children categorized as Level II were found to approach their predicted maximum GMFM-88

score more slowly than those children categorized as Level I or III[44]. There was no significant difference in the rate at which children in Levels I, III, IV, and V approached their predicted maximum GMFM-88 score[44]. The results showed that, with the exception of Level II, the curves begin to plateau around the age of 7 years indicating that by the middle of childhood children with CP stop making significant changes in their gross motor function abilities that are measured by the GMFM-88[44]. However, this does not indicate that CP children stop becoming more functionally advanced (i.e. the children are still able to improve their ability to complete tasks that reduce the need for assistance by a caregiver such as being able to transition from a wheelchair to a bed without assistance)[44].

After initial proof that the mathematical model was accurate enough to generate proper gross motor function curves, a second set of gross motor function curves were created. However, instead of using GMFM-88 scores, GMFM-66 scores were used[45]. It could be speculated that the now widely cited gross motor function curves were generated using the GMFM-66 rather than the GMFM-88 used previously in order to produce more meaningful data with an interval scale in order to improve the interpretability of the scale by assigning each unit the same meaning rather than using a scale which gives the same amount of significance to each type of skill tested. Once again, the predicted limit of the GMFM-66 score increased as functional GMFCS level increased[45]. In order to better interpret the results portrayed on the gross motor function curves, age-90s were calculated for each GMFCS level[45]. Age-90 is the age in years at "which a children are expected to reach 90% of the motor development potential", and therefore a smaller age-90 value indicates a faster rate of motor development[45]. The data indicated that children with CP classified as Levels III, IV, and V (which had age-90s of 3.7, 3.5, and 2.7, respectively) had significantly faster rates of motor function development than those classified as Level I (which had

an age-90 of 4.8)[45]. The data also indicated that children with CP classified as Level II (which had an age-90 of 4.4) had similar rates of motor function development than those classified as Level I[45]. Again, it is important to note that faster rates of development do not indicate that a child will have a higher level of gross motor function; only that the child will reach their maximum GMFM-66 score faster[45]. With the development of the newer gross motor function curves, expected GMFM-66 limits were calculated along with ranges to include 50% of the children's limits for each GMFCS level[45]. The GMFM-66 limit for children classified of GMFCS Level I was 87.7 with the 50% range of 80.1 to 92.8[45]. The GMFM-66 limit for children classified of GMFCS Level II was 68.4 with the 50% range of 59.6 to 76.1[45]. The GMFM-66 limit for children classified of GMFCS Level III was 54.3 with the 50% range of 48.5 to 60.0[45]. The GMFM-66 limit for children classified of GMFCS Level IV was 40.4 with the 50% range of 35.6 to 45.4[45]. The GMFM-66 limit for children classified of GMFCS Level V was 22.3 with the 50% range of 16.6 to 29.2[45].

To further improve the interpretation of the gross motor function curves, 4 of the 66 items of the GMFM-66 were chosen to be labeled on the curves at the GMFM-66 score in which a child with CP is expected to have a 50% chance of being able to complete the task[45]. Many items of the GMFM-88 had already been investigated in order to mathematically determine the GMFM-88 score at which a child had a 50% and 95% chance of completing the task successfully[44]. Items 21, 24, 69, and 87 of the GMFM were chosen[45]. Item 21 of the GMFM assesses the ability of a child to lift and maintain his or her head in a vertical position for 3 seconds while the child's trunk is supported by a therapist[42]. It was found that a child with a GMFM-66 score of 16 would have a 50% chance of being able to perform this task[45]. The gross motor function curves indicate that children with CP categorized in Levels I, II,

III, or IV should be able to complete this task rather early in life, while average children with CP categorized as Level V should be able to complete this task at roughly the age of 2 years[45]. Item 24 of the GMFM assesses the ability of a child to maintain sitting unsupported with his or her arms free for 3 seconds[42]. It was found that a child with a GMFM-66 score of 32 would have a 50% chance of completing this task successfully[45]. The gross motor function curves indicate that this task is achievable by children categorized as Levels I, II, or III, while Level IV children should develop this skill much later and Level V children rarely develop this skill[45]. Item 69 of the GMFM assesses the ability of a child to walk forward for 10 steps without any support[42]. It was found that a child with a GMFM-66 score of 56 would have a 50% chance of completing this task successfully[4]. The gross motor function curves indicate that this task is often only achievable by children categorized as GMFCS Levels I and II[45]. Item 87 of the GMFM which assesses the ability of a child to walk down 4 steps with alternating feet without holding on to a railing[42]. It was found that a child with a GMFM-66 score of 81 would have a 50% chance of completing this task successfully[45]. The gross motor function curves indicate that this task is probably only achievable by children categorized as GMFCS Level I[45].

4.7 Development of Tabulated Reference Percentiles

Using the gross motor function curves created in 2002[45], reference percentiles were created to approximately evaluate a child's gross motor abilities (as determined by the GMFM-66) compared to averages for the child's GMFCS level and age[46]. The same data set used to construct the 2002 gross motor function curves was used to create the reference percentiles[46]. This data set is thought to properly represent the population of children with CP that most therapists in North America and Europe would likely treat[46]. Since therapeutic interventions were not controlled in Rosenbaum et al.'s study, the sample contained children provided with a variety of accepted medical,

orthopedic, and developmental therapy services (with the exception of dorsal rhizotomies, botulinum toxin, and intrathecal baclofen because at the time of the initial study these were newer and not readily available therapies with unknown effects)[45, 46]. The original data set was longitudinal with children younger than 6 years of age being evaluated every 6 months and children 6 years of age or older being evaluated every 9 to 12 months[45]. This meant that the data sometimes included multiple GMFM-66 scores for a child during the same year of age. The method chosen to create the reference percentiles, the LMS method of Cole and Green, required that the data be cross sectional rather than longitudinal[46, 47]. In order to create a cross sectional data set, age bands for each year of age from 2 to 12 years were created, and only one observation at each age was used for each child in each age band[46]. The LMS method was chosen for its ability to produce smooth reference curves that include the fluctuating variability and skewness of the cross sectional sample[46]. In order to achieve the proper degree of smoothness for LMS curves, there must be a balance in smoothing out irregularities from sampling error and not removing clinically significant features[46]. If the model is well fitting, "the observations should conform to a standard normal distribution at any given age after LMS transformation"[46]. A separate LMS percentile was created for each GMFCS level[46]. The reference percentile curves for each of the GMFCS levels show the estimated percentile curves for the 3^{rd}, 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, 95^{th}, and 97^{th} percentiles with an age range from 2 to 12 years of age[46]. This may be seen in Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5 for GMFCS Levels I, II, III, IV, and V, respectively. Approximate percentiles may be determined from consulting the correct figure for the child's GMFCS level and visually interpreting the estimated percentile[46]. However, the tabulated reference percentiles are provided via an online resource should greater accuracy be desired[46].

Due to the large, longitudinal data set, the stability of the percentiles over time was able to be evaluated. For children with multiple GMFM-66 observations, 2 of the measurements were selected[46]. The percentile for each observation was determined, and the means and standard deviations of the differences between the percentiles were calculated for each of the GMFCS levels[46]. The mean change in percentile between observations for GMFCS levels I, II, III, IV, and V were 3.0, -0.8, 3.3, 2.5, and 3.6 respectively, with standard deviations of 15.6, 15.5, 12.4, 11.8, and 13.2, respectively[46]. A child classified as GMFCS levels I, II, III, IV, or V will have a 20% probably of a percentile change of ±4.0, ±3.9, ±3.1, ±3.0, or ±3.3, respectively, between assessments[46]. A child classified as GMFCS levels I, II, III, IV, or V will have a 50% probably of a percentile change of ±10.5, ±10.5, ±8.4, ±8.0, or ±8.9, respectively, between assessments[46]. A child classified as GMFCS levels I, II, III, IV, or V will have a 80% probably of a percentile change of ±20.0, ±19.9, ±15.9, ±15.1, or ±16.9, respectively, between assessments[46]. Thus, the expected variability in a child's percentile over time is highest for the GMFCS levels I and II, with high variability expected for children in all GMFCS levels[46].

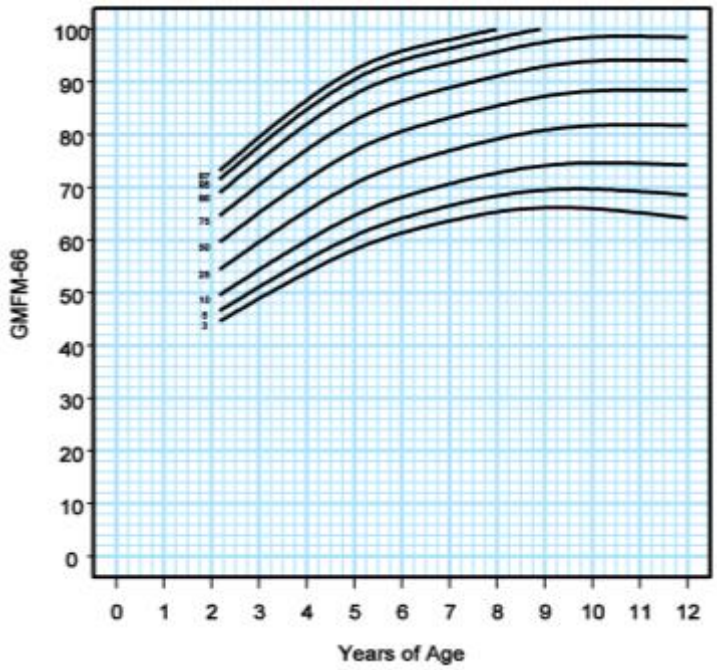

Figure 1. GMFM-66 Percentiles by Age: GMFCS Level I[48].
From: Hanna SE, Bartlett DJ, Rivard LM, Russell DJ. Tabulated reference percentiles for the 66-item Gross Motor Function Measure for use with children having cerebral palsy, April 2008, available at www.canchild.ca. Used under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 Canada (https://creativecommons.org/licenses/by-nc-sa/2.5/ca/).

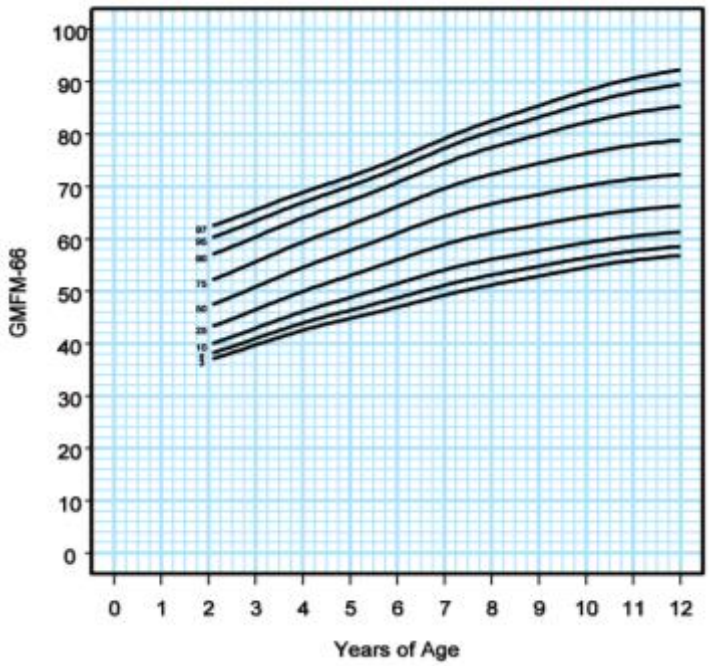

Figure 2. GMFM-66 Percentiles by Age: GMFCS Level II[48].
From: Hanna SE, Bartlett DJ, Rivard LM, Russell DJ. Tabulated reference percentiles for the 66-item Gross Motor Function Measure for use with children having cerebral palsy, April 2008, available at www.canchild.ca. Used under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 Canada (https://creativecommons.org/licenses/by-nc-sa/2.5/ca/).

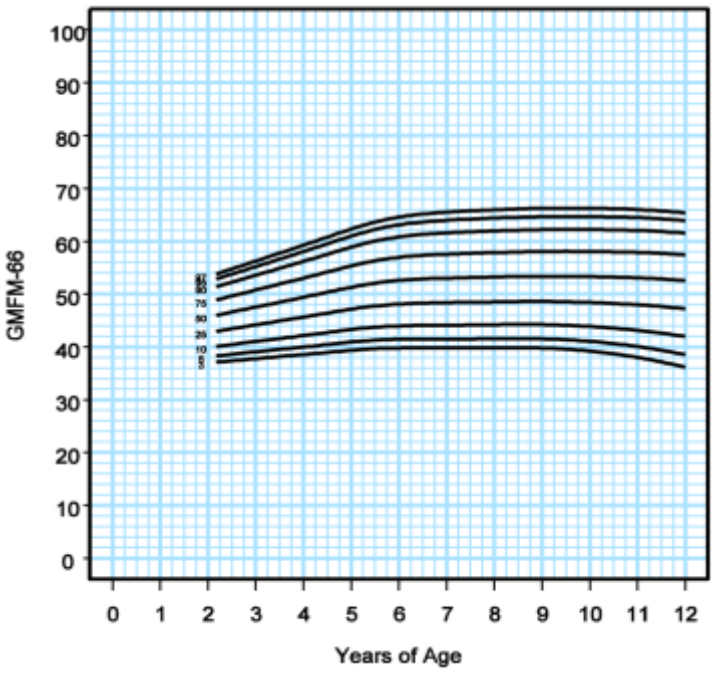

Figure 3. GMFM-66 Percentiles by Age: GMFCS Level III[48].
From: Hanna SE, Bartlett DJ, Rivard LM, Russell DJ. Tabulated reference percentiles for the 66-item Gross Motor Function Measure for use with children having cerebral palsy, April 2008, available at www.canchild.ca. Used under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 Canada (https://creativecommons.org/licenses/by-nc-sa/2.5/ca/).

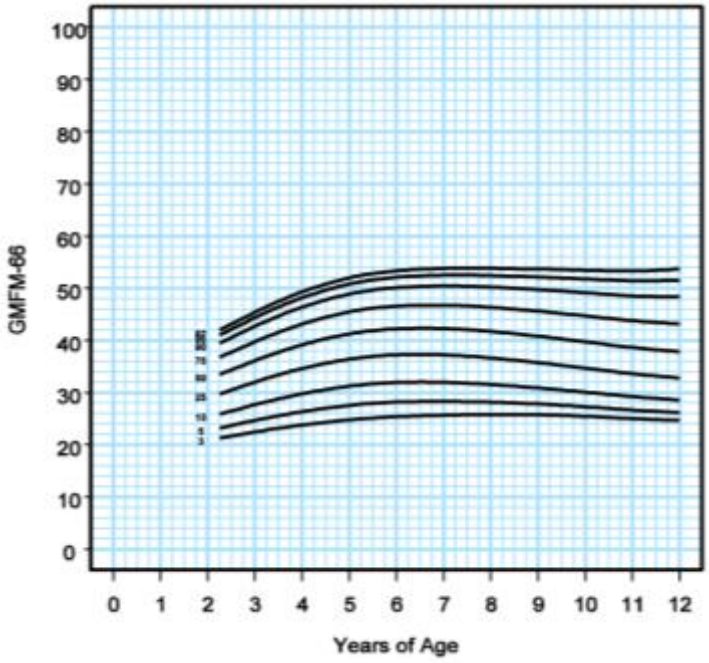

Figure 4. GMFM-66 Percentiles by Age: GMFCS Level IV[48].
From: Hanna SE, Bartlett DJ, Rivard LM, Russell DJ. Tabulated reference percentiles for the 66-item Gross Motor Function Measure for use with children having cerebral palsy, April 2008, available at www.canchild.ca. Used under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 Canada (https://creativecommons.org/licenses/by-nc-sa/2.5/ca/).

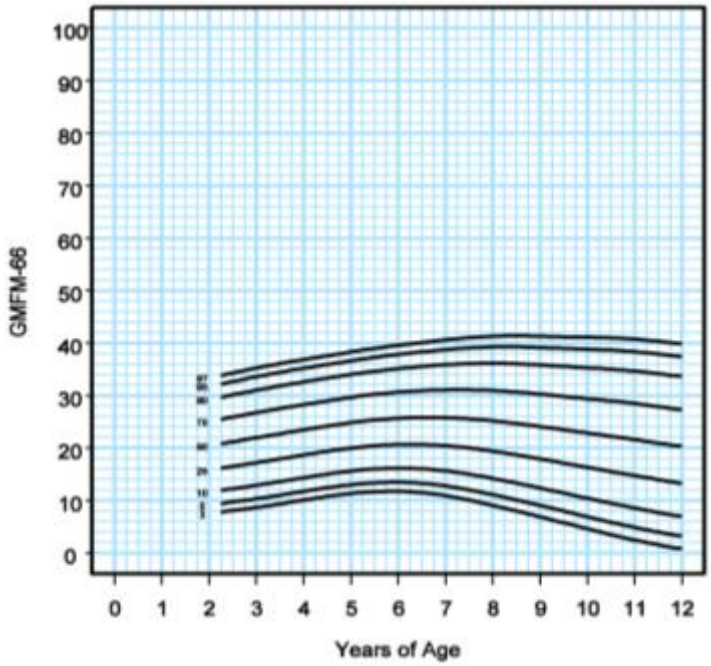

Figure 5. GMFM-66 Percentiles by Age: GMFCS Level V[48].
From: Hanna SE, Bartlett DJ, Rivard LM, Russell DJ. Tabulated reference percentiles for the 66-item Gross Motor Function Measure for use with children having cerebral palsy, April 2008, available at www.canchild.ca. Used under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 Canada (https://creativecommons.org/licenses/by-nc-sa/2.5/ca/).

4.8 Limitations of the GMFCS

While this classification system is adequate at broadly classifying patients with CP into groups, the classification system itself has many drawbacks. Firstly, since this system only seeks to classify gross motor function, only the skills relating to sitting, standing, walking, running, and jumping are evaluated[10]. While these are important skills, this classification system lacks any assessment of upper body movement (excepting that of the ability to hold trunk upright). It also lacks the assessment of the quality of movement performed. Secondly, this classification system does not require any training to administer. Although this may seem like an advantage, this increases

variability between raters and leaves raters with questions regarding children who appear to fall into multiple levels. This classification system also lacks the evaluation of quantitative metrics such as the ability to extend the legs to a certain degree or to take so many steps in a row without assistance.

Chapter 5
Conductive Education

5.1 History of Conductive Education

Conductive Education (CE) was created by Andras Peto in Budapest, Hungary in 1948 to provide education for children that were non-ambulatory and were unable to attend mainstream schools[12, 49]. Peto based many of his ideas about learning to move on the work of Nikolai Bernstein, whose work is widely credited for offering a considerable amount of the scientific foundations to the major motor learning theories that are the basis of current traditional therapy treatments[12, 14]. The Peto Institute was created in Budapest, Hungary, and it continues to operate today[12]. Both Peto and his successor as the director of the Peto Institute, Dr. Maria Hari, believed that many children with CP could learn to perform their own self-care tasks and learn to walk if they were taught with a program that included proper instruction, motivation, and opportunities to practice their skills throughout the day[12]. CE became an international educational approach after therapists and other health professionals began creating programs in their own countries after training at the Peto Institute[12]. Parents who wished to involve their children in CE programs also increased the international reach of CE by bringing conductors from Hungary to work with their children[12]. CE was initially brought to the United States in the early 1980s by a pediatrician who had observed CE programs in London[12, 50]. The United Cerebral Palsy of New York City established the first program based on CE that was staffed by American teachers and therapists in 1989[12, 50]. Despite this start, most CE centers in the United States and Canada are exclusively staffed by conductors trained in Hungary[12]. Additionally, most of the CE centers in the United States were created

by parents of children with CP [12]. For example, the Conductive Education Center of Orlando (CECO) was established in 2001 by Joe and Vicky Raymond after learning about the CE program[51]. The Raymonds brought a conductor from Hungary to work with their child and a handful of other children for six weeks[51]. After witnessing the progress made by the children, a year round program was immediately established[51]. It is important to note that CE programs outside of Hungary have been modified in order to conform to the different social, cultural, medical, and educational systems in each country[12]. In Hungary, CE is offered traditionally in a residential setting; however, outside of Hungary CE based programs may be offered in the form residential programs, baby programs, school day programs, or week long camps[13]. With such variation in the types of programs offered, the programs also have variations in which children are eligible based on their level of motor function[13].

5.2 Characteristics of Conductive Education Based Programs

It has been said that the best practices in traditional therapy include interventions which improve adaptive functions, improve muscle length, improve muscle strength, improve fitness, and prevent secondary impairments[12, 52]. CE addresses each of these areas by practicing and repeating tasks, working to improve motor control via the methods described in the next section, stretching the muscles, strengthening the muscles, using task analysis, and adapting tools or parts of tasks in order to promote function[12, 14, 53]. In traditional therapies, group therapies are only typically available to younger children[12]. Conversely, traditional CE based programs are always conducted in a group setting[12, 13]. The group setting has even been deemed to be an essential part of CE[12, 14]. While traditional therapists have specialties on which their therapies are based (i.e. occupation therapists work on upper limb

function while physical therapists work on mobility), CE conductors simultaneously promote each child's self-care goals, mobility, and social skills while integrating them into the program's daily activities[12-14]. Traditional therapists tend to work more with medical and scientific models and are trained in the use of evidence based practices and standardized measures (such as the GMFM-66 and GMFCS) [12]. CE based programs typically utilize education based models which result in a wide variety of outcomes, including academic skills, social skills, communication skills, and motor function skills, making comparisons between the results of CE and traditional therapies very difficult[12, 13].

5.3 Principles of Conductive Education

CE is a group program with the aim of developing an orthofunctioning personality[12]. An orthofunctioning personality is characterized by having the capacity to adapt or to learn in order to adjust to the natural and social environments throughout life[12, 54]. Orthofunction is the ability to respond to and solve the social demands, biological demands, and other problems of daily living in order to live as independent of a life as possible [12-15]. Orthofunction is the ability to "participate and function in society despite" disability, and it is considered as the opposite of dysfunction[12, 13, 55]. The philosophy of orthofunction differs from traditional thinking in terms of rehabilitating motor function in that it encourages an assortment of methods that are dependent on the individual child's abilities and differing environments in order to achieve functional goals[13, 14]. The group setting creates a motivating and accepting environment in which the children are able to create friendships and practice tasks[12]. Ideally, the children are grouped together based on functional abilities, individual needs, rates of progress, and background[12, 56]. The individual performance of each child within the group and the general ability level of the group are used to determine educational goals[13, 14]. The group setting also

provides children with the ability to learn from other children that have similar functional abilities via the imitation of approaches used by the other children to complete tasks[12].

The motivating environment of CE programs is further enhanced by the "facilitations" and routines of the CE program[12]. The facilitations enable the children to perform an activity autonomously, and the facilitations include appropriate physical and verbal cues, rhythmic intentions, and equipment required for tasks to be completed as independently as possible[12]. The facilitations will be further explained in the next section.

5.4 Conductive Education Methods

Despite vast differences in CE based programs internationally, all of the programs have certain elements in common. Each program is provided in a group setting with highly structured programs that utilize task series, rhythmic intentions, and specialized equipment[13]. The conductors, rhythmic intentions, task series, structured programs, and specialized equipment are five unique practices used in CE programs[12].

Conductors lead the group through the daily activities while other staff members assist the individual children with their participation in each activity[12]. CE integrates both rehabilitation and education goals into a single program rather than having separate programs focused on education and rehabilitation[13, 57]. In the traditional CE programs, the conductor acts as both the teacher and the therapist[13]. The conductor is typically responsible for selecting the children for the program and developing the curriculum for the program[13]. The conductor must be aware the individual needs of each and incorporate those needs into the daily activities[12]. The conductor leads the group with rhythmic intentions, songs, and directions[12]. The

conductors and other staff members are expected to express positive attitudes and positively direct the children towards methods that will enable them to succeed at a task[12]. They encourage the children to perform each task as independently as possible and provide minimal physical assistance[13]. The conductors must be able to determine the cause of a child's difficulties during tasks through observation in order to further instruct the child in methods to successfully complete the task[12]. The conductor avoids reprimanding a child's unsuccessful attempts and instead reinforces the adaptations the child must make in order to complete the task[12].

The task series, one of the CE facilitations, teaches the children to be able to control their movements and also teaches the children new movements that will improve function during activities[12, 56]. The task series serves to break down an activity into a series of steps with each step representing an intentional activity instead of an isolated exercise[13]. Each task series is constructed with the idea that the tasks begin within the range of the child's current ability level and then become increasingly more difficult in order to achieve a functional goal[13]. Each child has several task series that are addressed throughout the program[12, 56]. For example, if a child has excessive movements of the head, arms, and legs, a task series would be designed that promotes the ability to control the excessive movements in various positions[12, 53]. The child would then learn to lie straight and still during the lying program[12, 53]. During the sitting program, the child might be provided with a horizontal bar in order to maintain stability and control the excessive movements[12, 53]. Another child might be having difficulty with elbow extension[12]. One task series for that child would include multiple opportunities to practice elbow extension such as sitting with the hands by the sides, sitting at a table with the hands outstretched forward, or lying with the hands by the sides while holding rings[12].

Rhythmic intentions, another CE facilitation, are verbal first person directions that are said when attempting a task[12]. The intent of the first person rhythmic intentions is to teach the children to talk themselves through their own movement learning[12, 53]. The spoken language acts as a cue for the "planning, execution, and completion of the motor requirements" required by a task[12]. Rhythmic intention has two parts: the intention, which is considered the planning phase, and performing the movement, which is the execution phase[54]. The rhythmic intentions are integrated into the task series and direct the child's intention and attention to completing the task while also promoting speech and bringing the group together through the rhythm set by the conductor[12, 13, 56]. Rhythmic intentions utilize the ability to learn via rhythm, repetition, and language[12]. The rhythmic intentions are rhymes or songs for younger children and spoken descriptions for older children based on the task series, and they may include repetition of keywords or counting[12, 55]. The language used and the tempo of the rhythmic intentions vary depending on the children's age, abilities, motor needs, cognitive needs, and emotional needs[12]. The ultimate goal is for the children to learn to describe to themselves what their bodies must do in order to complete a task and to then utilize this knowledge outside of the CE program[12].

The CE program utilizes specially designed equipment, in order to promote the child's self-efficacy and independence[12]. "Wooden plinths that look like slatted tables, wooden chairs with high ladder backs, wooden ladder back standing frames, wooden stools and blocks, parallel bars, steps, rods, plastic rings, arm bands, and large mirrors for the children to see themselves working" are all typical pieces of equipment used in CE programs[12]. The equipment is adaptable to each child's body dimensions (i.e. blocks may be used to adapt the chairs with ladder backs in order for each child to have the necessary seat depth and height required for proper posture while sitting)[12]. Each piece of equipment promotes maintaining stability in various positions through

the use of active grasping and the use of the hands during many transitional movements[12]. Traditionally, the use of other assistive devices and adaptive equipment including splints, walkers, or wheelchairs during the program was discouraged, but some programs do allow the use of these devices[13].

The structured programs contain tasks that are related to the development of self-care skills, functional mobility skills, cognitive skills, and social skills[12]. The structured programs are designed to have a routine of activities that meet the individual goals for each member of the group while providing continual learning of skills, practice of skills, and emphasis on age appropriate life skills[12, 53]. The CE program has routines for activities in the lying, sitting, and standing positions and the transitional movements to move from one position to another[12]. Incorporating the transitional movements into the routines allows for smooth and natural transitions between the activities[12]. Activities of particular importance, including certain life skills, are practiced during the proper program[12]. Eating and drinking may be practiced during the sitting program, while rolling over or removing socks may be practiced in the lying program[12]. A typical structured program will include a lying program, a sitting program, a standing program, a mobility program, toilet training, and other self-care tasks according the typical schedule for the children's day[12]. Each type of program within the structured program contains individual tasks to be practiced[12]. Throughout the structured program each child, based his or her individual needs and goals, is properly set up to participate in every task, and the previously mentioned facilitations are used to promote each child's learning[12].

5.5 Studies of Conductive Education

It has been claimed that 70% to 80% of the children at the Peto Institute attain the ability to function without the use of wheelchairs, specialized furniture, or ramps in

normal age-appropriate social settings[49, 54, 58]. Many anecdotal stories detailing the belief in the effectiveness of CE programs have been published online, but the few peer-reviewed studies that have been published are unable to suggest that CE is more effective than traditional therapy methods[54, 59, 60]. Most of these published studies rely on the "subjective impression of parents and professionals as to whether the children have improved or not" as the basis of the evaluation of CE[54]. Unfortunately, there have been very few studies completed that include objective analysis in order to determine the effectiveness of CE on gross motor function.

A study conducted in Australia sought to compare a CE based program called the Yooralla program to an individual physiotherapy program[61]. The children studied ranged in age from 4 years to 7 years 1 month[61]. The children were split into two groups: the testing group that received the Yooralla program and a control group that received individual physiotherapy[61]. Due to the age range, both groups contained children that were preschool aged and school aged[61]. The amount of time the children spent in their respective programs was not controlled[61]. A variety of areas were studied including gross motor function, fine motor function, daily living activities, compliance, receptive language skills, and expressive language skills[61]. The children in the Yooralla program improved in every area, while the children in the individual physiotherapy program improved in every area except gross motor function[61]. Retrospective assessments based on the performance in all of the areas were made, and the results indicated that the children in the Yooralla program improved in all areas except for receptive language, while the children in the individual physiotherapy program regressed in all areas except expressive language[61]. The children in the Yooralla group had a significant increase in their mean performance in the areas of gross motor function, fine motor function, and daily living activities[61]. Conversely, the children in the individual physiotherapy group had a significant

decrease in their mean performance in those same areas[61]. It was ultimately concluded from the study that CE based programs could be more effective than individual physiotherapy programs in improving motor function; however, more studies with adequate amounts of subjects and randomized control groups would be necessary to confirm these conclusions[61].

Another study conducted in Australia compared CE based programs and early intervention programs[62]. The children in this study ranged in age from 19 to 69 months[62]. A control group was comprised of the children in the study who were currently enrolled in 4 separate center based early intervention programs that utilized traditional approaches to special education and therapy[62]. Of the early intervention programs, 3 provided group therapy sessions while only 1 provided individual therapy[62]. The testing group was comprised of children from 5 separate CE based programs which met at a minimum 5 mornings every two weeks and up to 5 mornings per week[62]. A variety of areas were studied including gross motor function, fine motor function, daily living activities, compliance, receptive language skills, and expressive language skills[62]. The results indicated that the children in the CE based programs consistently had larger improvements than the children in the control group[62]. The control group had decreases in performance in all of the areas except for fine motor function, but the CE based program group only had a small decrease in the area of expressive language[62]. This study was limited due to the sample size, the variations within the control group, and by the children being placed into groups via self-selection rather than randomization[62]. The study concluded that CE based programs exhibited trends of greater improvement in almost all of the areas evaluated when compared to the early intervention programs[62].

A later study conducted in Australia compared CE based programs to traditional therapy approaches for children ranging in age from 12 months to 36 months[58]. It

was noted that the results from this study may not apply to older school-aged children[58]. In the study, children were tested before and after participating in either a CE based program or a traditional therapy program for 6 months[58]. Some of the parents of children in the study were not willing to be randomly assigned into either CE based programs or traditional therapies[58]. As a result, this non-randomized group of children was evaluated separately from the randomized group[58]. In order to directly compare the effects of the different programs, the weekly amount of traditional therapy was increased to approximately match the weekly amount of time required by the CE based program[58]. This was done to prevent any implications that a greater amount of hours spent in CE based programs were the cause of greater improvements[58]. For the randomized group, ultimately the average amount of hours spent by children participating in the CE based program was 75.6 hours, or 2.8 hours per child per week, for the duration of the study, while the average amount of hours spent by children participating in traditional therapy was 79.8 hours, or 2.9 hours per child per week[58]. For the non-randomized group, ultimately the average amount of hours spent by children participating in the CE based program was 86 hours, or 3.2 hours per child per week, for the duration of the study, while the average amount of hours spent by children participating in traditional therapy was 59 hours, or 2.2 hours per child per week[58]. It could be inferred that the weekly hours spent in the traditional therapy and CE based program by children in the non-randomized group more closely represent the difference in weekly time commitment required for each type of therapy. Various assessment tools including the Vulpe Assessment Battery and GMFM were utilized to determine changes in a wide variety of areas including gross motor function, cognitive abilities, and daily activities[58]. There was a pattern of overall improvement for children in both the randomized and non-randomized groups and in both the CE based program group and traditional therapy group in the areas of cognitive ability, feeding, play, expressive language, receptive

language, gross motor skills, fine motor skills, and organizational behaviors[58]. The original GMFM was used to evaluate gross motor function[58]. Significant improvements were found in the dimensions of crawling and kneeling, sitting, and standing, as well as the total GMFM score for both children in the CE based program and children in traditional therapy within the randomized group[58]. There were also trends of improvement within the randomized group in the lying and rolling, and walking, running, and jumping dimensions, but the results were not significant[58]. No significant difference was seen between children in the CE based program and children in traditional therapy in the randomized group[58]. Significant improvements were found in the dimensions of lying and rolling, sitting, standing, and walking, running, and jumping, as well as in the total GMFM score for both children in the CE based program and children in traditional therapy in the non-randomized group[58]. For the non-randomized group, children in traditional therapy had significantly higher scores in the sitting, crawling and kneeling, standing, and walking, running, and jumping dimensions than the children in the CE based program[58]. For the non-randomized group, children in traditional therapy also had much greater improvements in scores in the lying and rolling dimension, standing dimension, and total GMFM score[58]. Overall the GMFM results indicated that the children in traditional therapy in the non-randomized group had the largest increases in GMFM scores[58]. However, it should be noted that these children typically began with higher GMFM scores that appear to correlate with mid-scale functionality[58]. As stated previously in section 3.3 Identifying and Correcting Limitations of the GMFM-88, children who initially had mid-scale functionality have a much greater probability of a change in GMFM scores over time[8].The study ultimately concluded that the children made similar progress in the variety of areas studied regardless of whether they participated in the CE based program or the traditional therapy program[58].

A study conducted in Canada set out to determine which outcome measures would be best suited for determining physical, psychosocial, and functional changes in children with CP participating in a full-day school-based CE program[59]. The children in the program were all classified as GMFCS Level III, IV, or V and were between the ages of 4 and 8 years[59]. The GMFM-88 and GMFM-66 were among the outcome measures tested for their responsiveness[59]. The change in the mean GMFM-88 total score for the children was 6.5%, while the change in the mean GMFM-66 total score was 3.9[59]. Unsurprisingly, the study found that the GMFM-66 was found to have large responsiveness while the GMFM-88 was found to have medium responsiveness[59]. Although this study was not intended to demonstrate the effectiveness of a school-based CE program, the results from this study do indicate that participation in this type of program will result in increased gross motor function.

A study conducted in Hong Kong was performed in order to determine the frequency of the occurrence and practice of gross motor skills in a full-day school-based CE program while also determining the amount of achieved individualized gross motor function goals[63]. Children with CP with ages ranging from 42 to 72 months and an average GMFCS Level of III were each observed 4 times throughout the school year by an independent pediatric physical therapist who was not involved in the CE program[63]. Observed class activities (i.e. "arrival/departure, lesson, fine motor/art/sensory, gross motor, free play, story time, tea time, clean-up, toilet, transition"), gross motor behaviors (i.e. "lying, assisted sitting, independent sitting, kneeling, quadruped, assisted standing, independent standing, and squatting"), mobility behaviors (i.e. "rolling, creeping, knee walking, assisted walking, other movement, and dependent mobility"), and transfer behaviors (i.e. "rolling, in and out of floor sitting, in and out of chair sitting, in and out of standing, other transfers, and dependent transfer") were recorded for each child on that individual child's observation day[63].

The rates of gross motor behaviors and daily activities for each observation day were determined to have no statistically significant differences[63]. The results showed that lessons were the principal classroom activity with an average of 32.1 instances per hour, while transitions occurred at an average of 25.3 instances per hour and gross motor time occurred at an average of 18.4 incidences per hour[63]. The most prevalent stability gross motor behaviors were assisted sitting with an average of 59.9 incidences per hour, independent sitting with an average of 27.8 incidences per hour, and assisted standing with an average of 19.4 incidences per hour[63]. The most prevalent transfer gross motor behaviors were in and out of standing transfers with an average of 4.5 incidences per hour and other transfers with an average of 3.0 incidences per hour[63]. The most prevalent mobility gross motor behavior was assisted walking with an average of 8.3 incidences per hour[63]. Two individualized gross motor objectives were determined for each of the children[63]. These objectives were mostly dynamic mobility activities that involved making a transfer, walking, or climbing stairs[63]. At the end of each term, a new objective would be given to the child provided that the previous objective had been achieved[63]. At the end of the first term, 15 of the 18, or 83% of the objectives had been achieved[63]. By the end of the next term, 2 of the 3 remaining original 18 objectives had been achieved for a total of 94% achievement of the original objectives[63]. Unfortunately, the last original objective was not achieved by the end of the study[63]. Of the 15 new objectives created after the first term, 11 of the new objectives, or 89% of the objectives, were achieved by the end of the second term[63]. The unachieved objectives consisted of stair climbing and independent walking with the assistance of a ladder frame[63]. Stair climbing was not observed on any of the observation days, which may have potentially led to failures in achieving stair climbing objectives[63]. It was noted that the children were either sitting with assistance or sitting independently for the majority of the day to an extent that was not expected and may potentially be a reason for previous

systematic reviews of CE being unable to determine that CE is more beneficial that traditional therapy programs[13, 60, 63]. The study did not use any standardized, comprehensive assessments so that instructional time would not be lost[63]. In the end, the children were able to achieve most of the objectives that were practiced throughout the school year, and conversely, the objectives that were not achieved were those that were not practiced throughout the school year[63]. This indicates that there is a "relationship between practice and the achievement of gross motor objectives"[63].

Chapter 6
Summary and Future Work

6.1 Cerebral Palsy Review

CP is a collection of disorders caused by disturbances in the developing brain before, during, or just after birth that affect the development of movement and posture resulting in limitations in activity[1]. In the United States alone, CP has a reported prevalence of 3 to 4 per 1,000 children and is the most common cause of motor disability in childhood[2-6]. Due to its prevalence, the need for proper methods to classify the gross motor function children with CP is intuitive. However, current classification systems do not accurately depict the gross motor function abilities and functionalities of children with CP.

6.2 Modifications for the GMFM-66

The GMFM-66 was designed to effectively evaluate gross motor function[64]. However, the GMFM-66 lacks clarity with respect to determining specifically what qualifies as a score of 1 (i.e. the child initiates movement but completes less than 10% of the task), 2 (i.e. the child partially completes the task by performing more than 10% but less than 100% of the task), or 3 (i.e. the child completes the task) for each task[7]. Biomechanical analysis could be used to quantify each task. For example, item 63 tests the ability to move into a squat position with the arms free[42]. If it is determined that achieving a joint angle at the knee of 90° is considered 100% completion of the task (a score of 3), it can be mathematically determined the range of joint angles required to achieve the other scores based on the initial joint angle. To

remove all subjective assessment, a properly programmed motion capture device could be used to record the task, analyze the results, and determine the result.

6.3 Modifications for the GMFCS

The GMFCS was created to be a standardized system for classifying the gross motor function of children with CP[10]. The GMFCS only investigates skills relating to sitting, standing, walking, running, and jumping and lacks any assessment of upper body movement (excepting that of the ability to hold trunk upright)[10]. The assessment of upper body motor function should be added to more properly classify children with CP. Training should be provided to decrease variation in assignment of GMFCS levels. Quantitative metrics, such as the ability to extend the legs to a certain degree or to take so many steps in a row without assistance, should be included within each level of the GMFCS in order to further distinguish between levels.

6.4 Mapping a Tool Utilizing a Modified GMFCS and GMFM-66 to Validate Conductive Education

The aim of CE is to develop an orthofunctioning personality[12]. In other words, the goal of CE is to teach children with CP to be able to respond to and solve the social demands, biological demands, and other problems of daily living in order to live as independent of a life as possible[12-15]. Most studies that have been done to determine the efficacy of CE utilize assessments with subjective scoring. The choice of these assessments made sense due to fact that CE is an educational model based program and these assessments provided ability to evaluate a variety of areas of development including gross motor function, daily living activities, cognitive abilities, and expressive language skills.

Achieving independence includes utilizing gross motor function skills in order to complete the tasks required for independence. Therefore, proper measurements of gross motor function abilities are required to validate CE based therapies. However, there are currently no adequate measures for detecting the type of motor improvements that CE aims to attain[12, 13]. Additionally, those involved with traditional CE based programs do not want to lose instructional time to complete standardized, comprehensive assessments. A modified version of the GMFCS that includes upper body motor function assessment should begin to be used to broadly classify children with CP participating in CE. This broad classification would help to determine how a child might progress during CE based on previous children within the same classification.

The GMFM-66 evaluates five dimensions of gross motor function[64]. The dimensions are lying and rolling, crawling and kneeling, sitting, standing, and walking, running, and jumping[64]. The CE program has routines for activities in the lying, sitting, and standing positions and the transitional movements to move from one position to another[12]. Many of the items tested by the GMFM-66 are practiced during the daily programs at CE based programs. On average only 13 of the GMFM-66's items need to be completed in order to accurately calculate the ability estimation[9]. If a motion capture device were able to record the children performing items from the GMFM-66 as they are completed within the CE program and extrapolate the score for each test using the previously defined metrics, then studies determining change in gross motor function using a validated outcome measure could be conducted without losing any instructional time.

Individualized gross motor objectives are created for each child in CE based programs. To obtain the gross motor objective, multiple sets of task series are created to break down an activity into a series of steps with each step representing an

intentional activity instead of an isolated exercise[13]. Each task series is constructed with the idea that the tasks begin within the range of the child's current ability level and then become increasingly more difficult in order to achieve the child's functional goal[13]. As of now there are currently no adequate measures for detecting the type of motor improvements that CE aims to attain[12, 13]. Motion capture devices could provide proper methods to detect motor function improvements. If a motion capture device were able to be used in the classroom during the CE daily programs, the daily changes in completing the task series could be monitored. For example, if a child was working on improving elbow extension, and a task series was created for that child would include multiple opportunities to practice elbow extension such as sitting with the hands by the sides, sitting at a table with the hands outstretched forward, or lying with the hands by the sides while holding rings[12]. Using motion capture, the joint angle of the elbow could be measured daily during these activities and quantitative biomechanical data would demonstrate if elbow extension was being improved. A study using this type of data to demonstrate the improvement of motor function over time would allow for evidence based proof of the effectiveness of CE programs.

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