

Dissertation

Title: Does home-based progressive resistance or high-intensity training improve strength, function, activity or participation in children with cerebral palsy?

submitted by

Christian Schranz

MSc. BSc.

for the Academic Degree of

Doctor of Medical Science

(Dr. scient. Med.)

at the

Medical University of Graz

**Department of Pediatric and Adolescence Surgery /
Division of Pediatric Orthopedics**

under the Supervision of

Priv.-Doz. Dr.med. PhD Martin Svehlik

2019

Statutory Declaration

I hereby declare that this thesis is my own original work and that I have fully acknowledged by name all of those individuals and organizations that have contributed to the research for this thesis. Due acknowledgement has been made in the text to all other material used. Throughout this thesis and in all related publications I followed the “Standards of Good Scientific Practice and Ombuds Committee at the Medical University of Graz”.

07.02.2019, Graz

Acknowledgments

I want to thank my family for their continued support, all the Co-Authors, without their help the completion of this study would not have been possible; Martin Svehlik, Annika Kruse, Teresa Belohlavek, Markus Tilp, Thomas Pieber and Gerhardt Steinwender, as well as all the physiotherapists who assisted with any measurements, Astrid Angerbauer, Daniela Altmanninger and Tamara Dampfhofer. I am especially grateful to Jane Ferreyra, who improved the English language of the manuscript tremendously and ensured the work is coherent and easy to read. I would also like to express my gratitude to companies Ortho Aktiv and Schuster Schalk for their financial support and all other staff of the Medical University of Graz, University of Graz and LKH that contributed to this study. Finally, I want to thank the Doctoral Program for Medical Science at the Medical University of Graz and its doctoral school “Bone, Muscle and Joint” Doctoral for supporting me in my studies.

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List of Abbreviations

ASKc	Activities Scale for Kids Capacity version
ASKp	Activities Scale for Kids Performance version
AFO	Ankle Foot Orthosis
CP	Cerebral Palsy
GPS	Gait Profile Score
GMFCS	Gross Motor Function Classification System
HICT	High Intensity Circuit Training
HIIT	High Intensity Interval Training
ICF	International Classification of Functioning, Disability and Health
MAS	Modified Ashworth Scale
MPST	Muscle Power Sprint test
MTS	Modified Tardieu Scale
PODCI	Pediatric Outcome Data Collection Instrument
PRT	Progressive Resistance Training
VO ₂	Volume Oxygen

Disclosure

The following co-authors have contributed to the original research presented as part of this thesis.

Annika Kruse, University of Graz, Institute of Sport Science

Teresa Belohlavek, KAGES – University hospital Graz, Department of Pediatric and Adolescence Surgery

Gehardt Steinwender, Division of Pediatric Orthopedics, Dept. of Pediatric and Adolescent Surgery, Medical University Graz

Markus Tilp, University of Graz, Institute of Sport Science

Thomas Pieber, Division of Endocrinology and Diabetology, Dept. of Internal Medicine, Medical University Graz

Martin Svehlik, Division of Pediatric Orthopedics, Dept. of Pediatric and Adolescent Surgery, Medical University Graz

Part of this thesis was submitted for publication with the permission of all co-authors. The article has been accepted for publication by “Archives of Physical Medicine and Rehabilitation” under the same title as this dissertation¹. The licensing agreement with the journal allows the use of the work in subsequent work by the author if the article is cited, which covers the use in this thesis. The article is cited where appropriate throughout the manuscript.

All the data has been collected exclusively by the main author. No data of any co-author was used which means that no release by any co-author is necessary.

This thesis uses figures of other authors within the introduction. They are freely available online, free for non-commercial use or a license has been obtained. The figures are cited as such within the manuscript.

English Abstract

Objective: Does home-based progressive resistance training (PRT) or high intensity circuit training (HICT) improve strength, function, activity or participation in children with cerebral palsy (CP)?

Design: This was the first study on high intensity circuit training for children with cerebral palsy. This study was conducted as a randomized prospective controlled pilot-study.

Setting: Evaluation took place at the gait laboratory of the university hospital; training sessions were performed at home.

Participants: 22 children with CP (average age:12 years, 10 months, 19 Gross Motor Functions Classification Scale I, 3 Gross Motor Functions Classification Scale II) were randomly assigned either to PRT or HICT.

Interventions: The PRT-group trained with progressive overload while the HICT-group performed as many repetitions as possible within 30s-intervals (8-weeks, 3 times weekly in both groups).

Outcome measures: Outcome measures stretched over all domains of the International Classification of Functioning, Disability and Health and included muscle strength, Muscle Power Sprint test, Timed-stairs-test, 6-minute walking test, Gait Profile Score, Timed-up-and-go test and participation questionnaires.

Results: Only the HICT-group was able to improve strength. Furthermore, HICT-group scored better in the Muscle Power Sprint test while PRT-participants improved in the timed-stairs-test and Timed-up-and-go test. Finally, the HICT-group showed improvement in the subscale of the parent reported questionnaire. There was no change of any other measures of mobility or participation.

Conclusion: Both programs improved function specific to intervention. However, only HICT-group showed significant strength improvements. Compliance was decent in both groups, but the average training unit was shorter in the HICT-group. Both exercise programs showed functional benefits but HICT might be the preferable option for strengthening in highly functional children with CP.

German Abstract

Fragestellung: Verbessert ein progressives Widerstandstraining (Progressive Resistance Training = PRT) oder ein hoch-intensives Zirkeltraining (High Intesity Circuit Training = HICT), Kraft, Funktion, Aktivität oder Partizipation in Kindern mit Zerebralparese?

Studiendesign: Es handelt sich um die erste Studie die hoch-intensives Zirkeltraining bei Kindern mit Zerebralparese untersucht hat. Die Studie wurde als eine randomisierte, prospektive, kontrollierte Pilotstudie entworfen.

Umfeld: Die Untersuchungen wurden im Ganglabor der Kinderorthopädie des LKH-Graz durchgeführt. Die Kinder trainierten zu Hause.

Teilnehmer: 22 Kinder mit infantiler Zerebralparese (durchschnittliches Alter: 12 Jahre, 10 Monate, 19 GMFCS I, 3 GMFCS II) wurden zufällig entweder dem HICT oder dem PRT Training zugeordnet.

Interventionen: Die PRT-Gruppe trainierte mit einer progressiven Überlastung während die HICT-Gruppe so viele Wiederholungen wie möglich in 30 Sekunden durchführen musste. (8 Wochen, 3 mal pro Woche, dieselben Übungen in beiden Gruppen).

Messungen: Es wurden Messungen aus allen Domänen der International Classification of Functioning, Disability and Health durchgeführt. Diese inkludierten Muskelkraft, Muscle Power Sprint test, Timed-stairs-test, 6-minute walk test, Gait Profile Score, Timed-up-and-go-test und Partizipationsfragebögen.

Resultate: Nur die HICT-Gruppe zeigte eine Verbesserung der Muskelkraft. Weiters hat die HICT-Gruppe auch besser beim Sprinttest abgeschnitten während die PRT-Teilnehmer sich beim Timed-stairs-test und Timed-up-and-go test verbesserten. Zusätzlich hat die HICT-Gruppe sich auch bei Unterkategorien des Elternfragebogens verbessert. Es gab keine Veränderungen bei anderen Mobilitätsmessungen oder Partizipationsfragebögen

Konklusion: Beide Programme haben Funktion spezifisch zur Intervention verbessert. Allerdings gab es nur bei der HICT-Gruppe Kraftzuwächse. Die Einhaltung des Trainings war in beiden Gruppen gut, die durchschnittliche Trainingszeit war aber in der HICT-Gruppe deutlich kürzer. Beide Trainingsprogramme sind geeignet, um Funktion zu verbessern, aber das HICT-programm ist vermutlich die bessere Methode für Krafttraing bei Kindern mit Zerebralparese.

1. Introduction

1.1. Thesis overview

Children with cerebral palsy (CP) are weaker than their typically developing peers. As a result, strength training is an essential intervention for them. The golden standard of strength training is Progressive Resistance Training (PRT). PRT is an established and effective intervention to improve muscle strength in CP. However, the impact of PRT on functional ability is limited. Moreover, many childhood activities consist of bursts of intense activity and the rapid generation of force is reduced in children with cerebral palsy. High Intensity Circuit Training (HICT) is an intervention with intervals of high intensity combined with short breaks that leads not only to improvements of aerobic but also anaerobic capacity. Therefore, HICT might be more suitable than PRT for children with CP. Additionally, the effectiveness of home-based strength training on children with CP remains to be evaluated. This work examines the influence that home-based PRT and HICT interventions have on strength and function for children with CP.

1.2. Cerebral palsy

Cerebral palsy (CP) is “a disorder of movement and posture that is defined as a group of non-progressive motor impairments secondary to lesions or abnormalities of the brain” during the early stages of its development^{1,2}. The worldwide prevalence is around 3 per 1000 live births³. Cerebral palsy is a result of a non-progressive insult to the developing brain.

Cerebral palsy generally presents within the first 12 to 18 months of life (except the mildest forms) when issues of motor development such as asymmetric gross motor function, unusual muscle stiffness, or floppiness present themselves⁴. These disturbances in motor development will result in delayed motoric milestones. In addition to mobility impairments, children with CP may suffer from seizure disorders and impairment of sensation, cognition, and/or behavior⁵.

1.3. Classification based on motor abnormalities

Children with cerebral palsy are most often classified as spastic, dyskinetic, or ataxic based on their motor abnormalities⁶.

Spasticity is defined as a velocity dependent resistance to passive movement and spastic cerebral palsy is the most common type of CP⁷. The chapter on “Spasticity” (1.6.1) delves into further detail about this classification.

Dyskinetic CP occurs in 10-15% of the CP population. It includes several movement disorders with dystonia and athetosis being the most common⁸. Dystonia manifests itself through abnormal changes in muscle tone, which lead to a distortion of voluntary and involuntary movements. Athetosis includes involuntary movements of face, neck and distal extremities that consistently change direction.

Children with ataxic cerebral palsy have a diminished sense of coordination due to an injury to the cerebellum⁹. This injury impacts balance and controlled goal-directed movements¹⁰. Children with ataxic CP exhibit an unsteady, stomping gait and have difficulties with motor tasks¹¹.

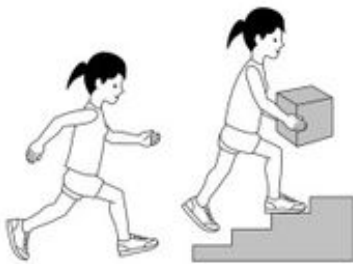
Many children experience multiple movement disorders which means that a singular classification is often not perfectly precise or reliable⁴. The children are classified based on the dominant disorder.

1.4. Topographical classifications

Cerebral palsy can be also classified based on the affected anatomical region. The most common form of CP is spastic diplegia, which primarily affects the lower extremities⁸. Children with hemiplegic CP are primarily affected on one half of their body⁹. These children are usually functional ambulatory. Tetraplegic cerebral palsy is the most severe form with severe limitations in all four limbs. Most children with tetraplegic cerebral palsy are not ambulatory⁹.

1.5. Gross Motor Function Classification System (GMFCS)

The Gross Motor Function Classification System (GMFCS) is an additional tool that classifies neurologic patients based on their activity limitation; it is frequently used in children with cerebral palsy and has prognostic value. The GMFCS objectively classifies the current gross motor function with a focus on the child's self-initiated movements like sitting and walking. The GMFCS classification system is divided into five levels, with level I representing the most independent group of patients and level V representing the group most severely limited in their mobility. A complete description of each level is presented in Figure 1¹².



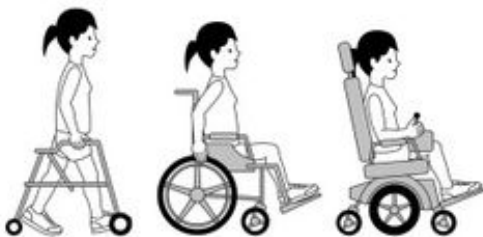
GMFCS Level I

Youth walk at home, school, outdoors and in the community. Youth are able to climb curbs and stairs without physical assistance or a railing. They perform gross motor skills such as running and jumping but speed, balance and coordination are limited.



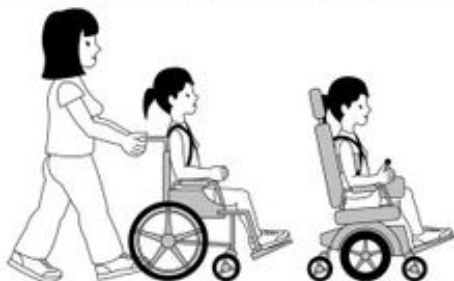
GMFCS Level II

Youth walk in most settings but environmental factors and personal choice influence mobility choices. At school or work they may require a hand held mobility device for safety and climb stairs holding onto a railing. Outdoors and in the community youth may use wheeled mobility when traveling long distances.



GMFCS Level III

Youth are capable of walking using a hand-held mobility device. Youth may climb stairs holding onto a railing with supervision or assistance. At school they may self-propel a manual wheelchair or use powered mobility. Outdoors and in the community youth are transported in a wheelchair or use powered mobility.



GMFCS Level IV

Youth use wheeled mobility in most settings. Physical assistance of 1-2 people is required for transfers. Indoors, youth may walk short distances with physical assistance, use wheeled mobility or a body support walker when positioned. They may operate a powered chair, otherwise are transported in a manual wheelchair.



GMFCS Level V

Youth are transported in a manual wheelchair in all settings. Youth are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements. Self-mobility is severely limited, even with the use of assistive technology.

GMFCS descriptors: Palisano et al. (1997) Dev Med Child Neurol 39:214-23
CanChild: www.canchild.ca

Illustrations copyright © Kerr Graham, Bill Reid and Adrienne Harvey,
The Royal Children's Hospital, Melbourne

Figure I: the different levels of the Gross Motor Function Classification Scale (Figure available with open access under the following citation¹³)

1.6. Natural progression

The natural progression of CP is a decline in function, especially during growth spurts in adolescence¹⁴. Factors that might be responsible for that are the increasing musculoskeletal problems as well as negative changes of the ratio between body mass and strength¹⁵.

A study by Day et al.¹⁶ showed that children with CP with good motor function at the age of ten are able to maintain the ambulatory activity for up to 15 years, after which a slow decline sets in. However, these results likely overestimate the natural progression of the disease because the children received treatment targeted at improving function prior to any decline¹⁶. Other studies investigating children without intervention demonstrated a decline in several important clinical gait parameters, decreases in key kinematic parameters, hip abduction and ankle flexion range of motion, timing of toe off, cadence and walking velocity^{17,18}.

As noted above, muscle weakness and the negative change of ratio between body mass and strength in adolescence are responsible for the progressive decline in mobility with age. While children with CP may have sufficient strength for walking in childhood, they will fall below the necessary strength threshold for ambulation much sooner (e.g. in adolescence or young adulthood) than typically developing peers¹⁹. Figure 2 illustrates this problem¹⁹.

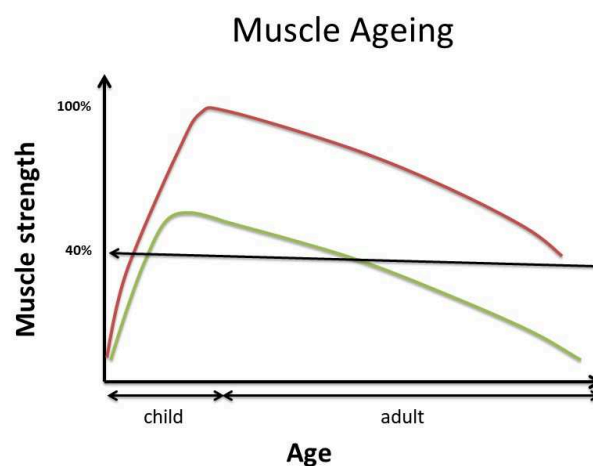


Figure 2: Muscle weakness in cerebral palsy: while children might have enough strength above the threshold to stay ambulatory, they will lose ambulation in their adulthood sooner compared to typically developed children¹⁹

1.6. Symptoms of cerebral palsy

The pathophysiological cascade of cerebral palsy includes positive and negative signs of the upper motor neuron pathology. The “positive signs” result from a loss of inhibition in the central nervous system and include features such as spasticity, co-contraction, clonus, hyper-excitability, and released primitive reflex patterns¹⁵. “Negative signs” include symptoms such as weakness, fatigability, loss of selective muscle control, poor balance, relative imbalance between agonists and antagonists across joints and sensory problems¹⁵. These negative signs are the consequence of limited connectivity between upper and lower motor neurons. The pathophysiological cascade is illustrated in Figure 3²⁰.

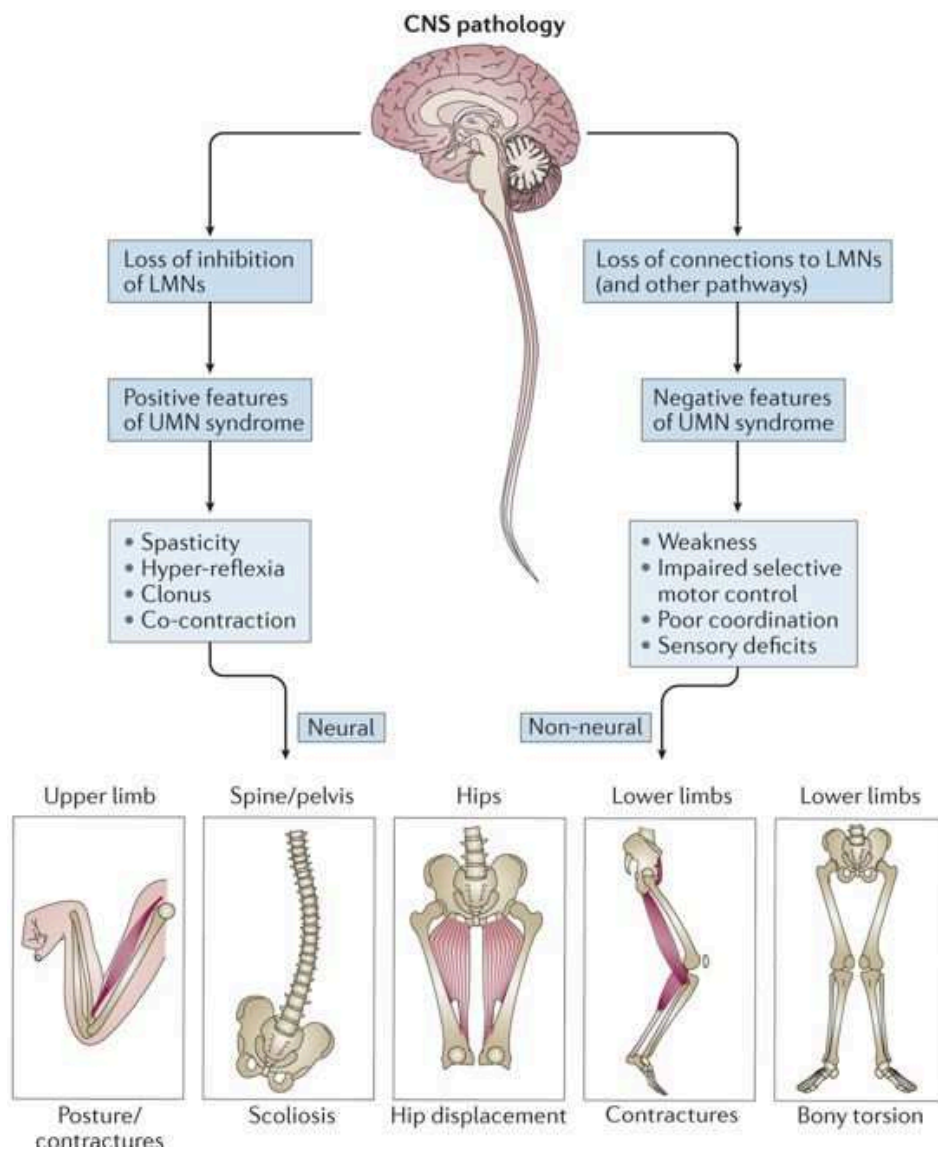


Figure 3 Pathophysiological cascade of cerebral palsy, how positive and negative signs both contribute to the symptoms of CP (Figure reproduced from an article by Graham et al.²⁰, a license was obtained from the publisher)

Both positive and negative signs together lead to the main pathologies of cerebral palsy like muscle shortening and joint instability. Historically, most interventions targeted positive signs such as spasticity because they were thought to be more harmful than negative signs²¹. However recent research has shown that intervention targeting positive signs such as dorsal rhizotomy leads to only limited functional improvement and that treating negative signs like muscle weakness correlate more closely to motoric function than treating positive signs²². Thus, negative signs of cerebral palsy might be more functionally debilitating.

1.6.1. Spasticity

Spasticity is the most common “positive” sign of cerebral palsy and a common consequence of upper motor neuron syndrome. Spasticity is a stretch reflex disorder that manifests itself as a velocity dependent increase in muscle tone to passively stretched muscle with exaggerated tendon jerks²³. The amount of muscle stretch is regulated by muscle spindles, which communicate the position of the muscle to the posterior nerve roots. Based on the detected position of the muscle an excitatory impulse adjusts the muscle to the desired length²⁴. Damage to the upper motor neuron reduces the cortical inhibitory input to descending reticulospinal and corticospinal tracts²⁵. The reduction of these signals prevents normal inhibition of reflex arcs within the spinal grey matter, which leads to spasticity and hyperactive reflexes²⁶.

As spasticity is velocity dependent, muscle stretch at a higher velocity results in increased muscle tone²³. Additionally, spasticity is also a length-dependent phenomenon. A muscle experiences a larger degree of spasticity when it is short compared to when it is long²⁷. Spasticity is predominately present in multiarticular muscles. Therefore, these muscles are more frequently contracted compared to monoarticular muscles and a more common target of surgical intervention¹⁵.

Spastic cerebral palsy is the most common form. The degree of spasticity in a child with CP is associated with improved functional performance in activities of daily living such as gait, feeding, washing, toileting, dressing, and motor learning^{25,28}. Consequently, a lot of the interventions for CP are directly targeted at reducing spasticity and the assessment of spasticity is an important clinical task.

There are several clinically applicable methods to assess spasticity; the Modified Ashworth scale (MAS) and the Modified Tardieu scale (MTS) are the two most common. The MAS

assesses the increase of muscle tone as a reaction to rapid movement. The MTS is a more extensive method that records the muscle reaction to predefined movement velocities²⁹. While the MAS is a quick and easy method to clinically assess spasticity, only the MTS can distinguish between soft tissue stiffness and spasticity.

1.6.2. Spastic muscle

Children with CP experience considerable changes in the architecture of their spastic muscles³⁰. A detailed chapter on skeletal muscle physiology can be found in the supplemental materials.

There is consistent evidence of reduced muscle size, as indicated by reduced muscle volume, cross-sectional area, and muscle thickness³¹ in children with CP. As a consequence, these children are considerably weaker than their typically developing peers³².

Additionally, children with CP suffer from reduced sarcomere length, fascicle length, and muscle belly length, which particularly impacts contraction speed³⁰. Finally, it is essential to consider the changes to the muscle fibre distribution. Children with CP have a decreased number of slow twitch muscle fibres and an increased number of fast twitch muscle fibres, which is consistent with higher levels of fatigability and lower levels of ambulation³³.

These changes in muscle tissue are accompanied by changes to the corresponding passive tissue³⁰. Ambulatory children with CP have a greater connective tissue fraction and more intermuscular and intramuscular fat compared to typically developed children³³. Additionally, there is also an increased amount of collagen in the connective tissue of children with CP, which correlates with increased spasticity and increases stiffness³⁴. The changes in active and passive tissue together result in increased stiffness of the joints and range of motion limitations, which is called a contracture³⁰. Contractures lead to further inactivity and pathologic muscular changes.

1.6.3. Muscle weakness

The most important “negative” sign of cerebral palsy is muscle weakness, the inability to generate appropriate muscle power. Children with CP are weaker in all major muscle groups of the lower extremities, especially the calf muscle³².

There are multiple factors that are responsible for the limited force production in CP like the morphology of spastic muscle, changes in motor drive (neurological disturbances), as well as biomechanical problems such as lever-arm dysfunction (1.6.4.).

The pathological changes to the muscle morphology of the spastic muscle have a direct impact on force production. A shorter, thinner, stiffer muscle with shorter fascicles will produce less muscle power. For more in-depth information on this topic refer to the last chapter (1.6.3. “Muscle architecture”)

Another important factor that promotes muscle weakness is deficient recruitment of motor neurons and, consequently, incomplete activation of the motor unit³⁵. While the activation of motor unit recruitment at low levels is similar to normally developing children, children with CP cannot recruit the high threshold motor units that are necessary for a maximal contraction, nor are they able to modify the firing rates of low threshold motor units³⁶. This reduction of high-threshold motor unit recruitment in children with CP also explains the structural adaptations in the predominance of fast twitch muscle fibers described in the previous chapter³⁶.

Additionally, children with CP tend to be less physically active compared to typically developing peers. Physical activity promotes muscle strength and improved functional performance³⁷. As a consequence, children with CP are weaker and regular physical activity is a worthwhile goal to improve health, function, and independence³⁸.

Muscle weakness is further exaggerated by mechanical issues due to range of motion restrictions or bony deformities that negatively impact the lever arm of a joint. If force cannot be applied at the optimal physiological angle, muscle strength is reduced³⁹. Details are provided in chapter 3.1.1. “Lever arm dysfunction”.

Muscle weakness in children with CP might be further negatively impacted by certain interventions, such as neurosurgical or orthopedic interventions. These interventions target “positive” signs like spasticity, but further diminish muscle strength²¹.

1.6.4. Lever arm dysfunction

In children with CP, short muscles, contractures, and changes in muscle architecture lead to an altered mechanical load. This abnormal load, in combination with muscle imbalances, can lead to secondary bone deformities (e.g. foot deformities), which subsequently lead to a

pathological change to the lever arm of the affected joint (lever arm dysfunction)³⁹. The optimal ratio of internal to external moment lever arm is essential for optimal force production of a muscle (see chapter 1.1).

Figure 6 presents the most frequent case of lever arm dysfunction in children with cerebral palsy; equinus gait. Picture A shows the ratio of moment arms for a typically developing child. In equinus gait (picture B the same force is applied much closer to the joint center which greatly reduces both moment arms⁴⁰. Why is a shorter moment arm problematic? The torque that is powering the joint is calculated by multiplying force and moment arm⁴¹. As a consequence, children with a shorter joint moment arm will have to produce considerably higher forces to achieve the same effect at the joint. Therefore, reducing this lever arm imbalance through targeted intervention is a key goal of most interventions. Picture C presents a child with CP after surgery where the lever arm is once again close to that of normally developed children⁴⁰.

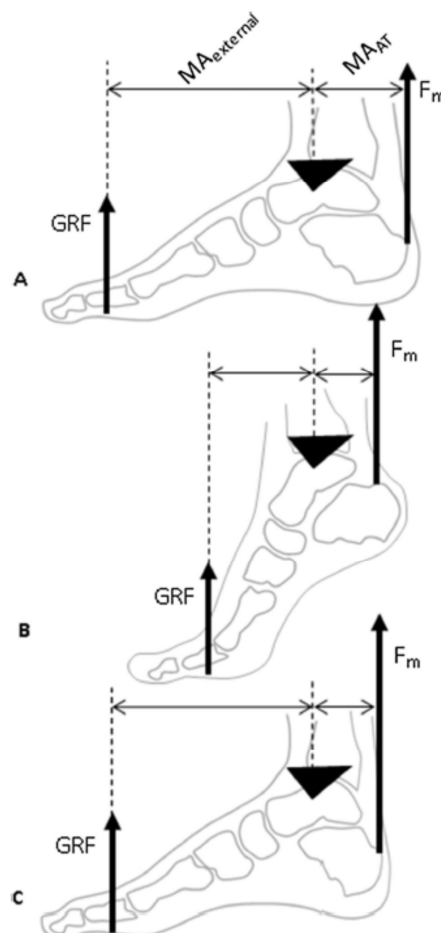


Figure 6: lever arm dysfunction in children with CP A) lever arm for sagittal ankle movement in typically developed children, B) the same lever arm in children with cerebral palsy, C) the lever arm of children with cerebral palsy after corrective surgery (Figure was reproduced from an article by Kalkmann et al. ⁴⁰, the distribution of the figure has been allowed for any non-commercial use by the publisher)

This altered level arm prevents the adequate transfer of forces and torques arising from the ground reaction force which may greatly affect motor function. Lever arm dysfunction should be understood and considered for each intervention to allow an optimal functional outcome³⁹.

1.7. Treatment of cerebral palsy

The primary goal in the treatment of cerebral palsy is the management of symptoms in order to achieve the best individual long-term outcome. This can be achieved through a combination of different interventions: physical, medical, surgical, pharmacological, and/or orthotics⁴². While most interventions will focus on the primary impairments that underlie the functional impairments, there is also an increased need for interventions that have a direct impact on the daily functional activities and participation of the children, such as constraint movement therapy, hippotherapy, and others⁴.

A multidisciplinary approach to treating CP is the gold standard. The broad range of different interventions requires medical specialists from a multitude of different fields for an optimal approach. These specialists cooperate with each other and work in unison to find a targeted approach with specified, individualized goals to reach the best possible outcome for the patient. The large range of intervention specialties is illustrated in Figure 7. While these specialties provide essential interventions for children with cerebral palsy (e.g. orthopedic surgical interventions), this study examines a conservative strengthening intervention, which is the focus of the following chapters.

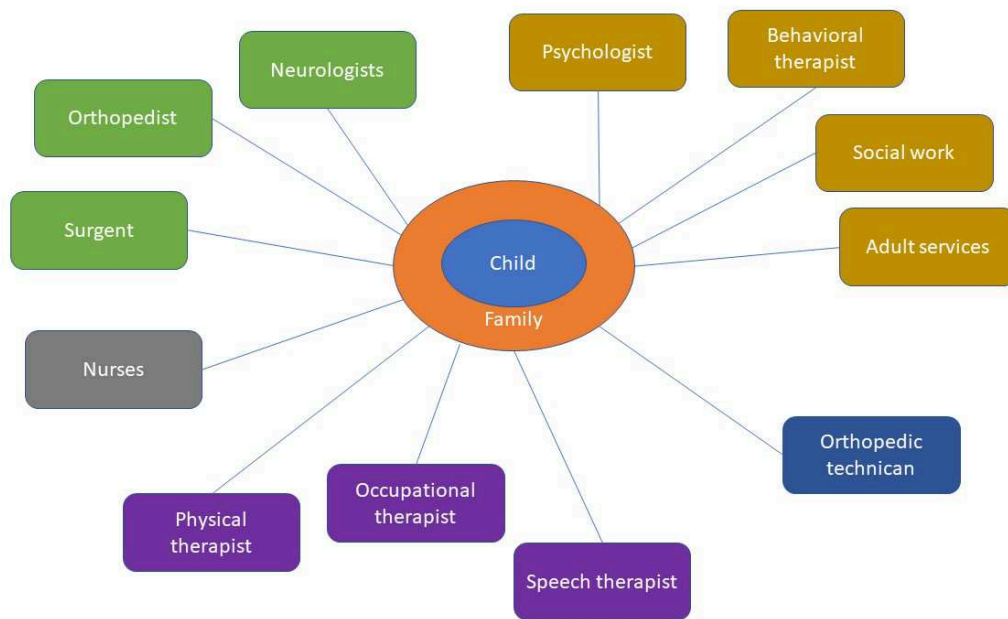


Figure 7: A broad interdisciplinary team is needed for the treatment of cerebral palsy uniting all sorts of specialties.

1.7.1. Conservative treatment

Conservative therapy should always be considered prior to any surgical interventions⁴³. Among the most common conservative approaches are physiotherapy, occupational therapy, speech therapy, and orthotic treatment⁴⁴.

Physiotherapy utilizes physical approaches to promote or maintain health⁴⁵. The main goals of physical therapy are to increase and improve motor skills, to maintain functional levels of movement, and the general management and minimization of contractures and deformities^{46,47}.

The most common physiotherapy interventions for children with CP target reduction of abnormal muscle tone, musculoskeletal problems (spasticity, weakness, muscle length), specific functional and activity goals, and improvement of physical activity in daily life⁴⁷. Physical therapy interventions that are effective for children with CP include balance exercises, gait training, neurofacilitation methods, constraint-movement therapy, sensorics integration, transfer training, and electrostimulation⁴⁸⁻⁵¹.

Physical therapy is often accompanied by occupational and/or logopedic therapy. Occupational interventions target fine motor skills (e.g. writing and drawing) and challenges faced in daily living (e.g. self-care, dressing, grooming, feeding)⁵². Approximately 20% of

children with CP have severe communication impairments^{49,53}. Speech therapy aims to improve the child's ability to communicate through speech, gesture, and/or communication aids⁵³.

Orthotic treatment is another frequently used conservative treatment in children with CP. It counteracts progressive joint and muscle contractures and improves function by restricting movement and increasing stability⁵⁴. The most common orthosis is an Ankle Foot Orthosis (AFO)⁵⁵ where the foot is maintained in a fixed position that ensures correct ankle-foot alignment and avoids contractures by slowly stretching the muscle⁵⁵. Multiple studies testing AFOs using gait analysis showed improved walking speed, cadence, stride length, and gait pattern.^{47,56,57}

1.8. Muscle strengthening

Children with CP are weaker than their typically developing peers^{1,58}. Improving and maintaining strength is an essential goal for children with CP. Strengthening, however, was previously not a recommended intervention as it might be impossible due to impaired selective control and might negatively impact spasticity and muscle tightness^{1,21,58-61}. Additionally, the small functional gains were discouraging compared to larger functional improvement for interventions targeting spasticity²¹.

However, recent research has shown that exercise training can increase strength in children with CP without increasing spasticity or any other adverse effects^{1,62-64}. Muscle weakness is also more closely correlated with muscle function than spasticity^{1,65,66}. Strengthening is now a mainstay of pediatric intervention as it can alter the prognosis of the child's future mobility and positively impact both the level of disability and participation^{1,67}.

Strengthening does not only enhance muscular fitness, it leads to additional general health benefits such as significantly better cardiometabolic risk factor profiles, lower risk of cancer, and more^{68,69}.

1.8.1. Progressive resistance training (PRT)

The golden standard for muscle strengthening in children with cerebral palsy is progressive resistance training (PRT). It aims at strengthening the muscle by progressive overload.

The initial load can be assessed using a 10-repetition maximum test. This test evaluates the maximum load for 10 repetitions of an exercise; load is increased or reduced until the child is able to complete the ten repetitions⁷⁰. The load is progressively increased during the training.

Once the child is able to complete the required number of repetitions in several consecutive training sessions the load will be increased. The amount of the increased load is predefined based on the child's body weight. PRT was originally developed for young, healthy adults to improve athletic performance and is frequently used to promote physical exercise in the community. Progressive resistance exercises have proven to be effective in physiotherapy⁵⁹.

While PRT is successful in improving strength in children with CP there is conflicting research on its functional benefits^{62,71}. Two large randomized controlled trials (RCTS) have been published by Scholtes et al. and Taylor et al.^{62,72}. Taylor et al. employed a 12-week progressive resistance program for 48 children (GMFCS II and III, mean age 18y 1 month), who were either randomized to the intervention or usual-care control. Participants trained twice weekly, completing three sets of 10-12 repetitions of each exercise with a break of two minutes in between sets. Exercises were individualized and targeted to deficits identified in gait analysis. While they were able to show a 27% increase in strength in the targeted muscle groups this increase did not result in improvements of any functional measures such as walking performance, gait kinematics, or muscle performance, but they were able to show improvements in participant-rated measures of mobility. The authors suggest that the potential stimulus might not have been sufficient enough and that there are other aspects of walking such as impaired motor planning impaired balance, postural control, spasticity and limited range of motion that might have been improved by the intervention but were not captured by the outcome measures⁷².

Another randomized control trial by Scholtes investigated 51 children with spastic uni- and bilateral cerebral palsy⁶¹. They were randomized to an intervention group which received 12 weeks of progressive resistance training three times a week with a circuit of five functional exercises and a control group. They found strength improvements (8%) in total hand-held isometric muscle strength in the training group. However, these strength improvements were not accompanied by mobility improvements (as measured by the GMFM-66). They suggest that strength improvements might have been too low for functional improvement or the number of individual muscles gaining strength was too limited⁶¹.

In contrast to these randomized trials there were other studies that did report some form of functional improvement after progressive resistance training. While the quality of the evidence in these studies was considerably lower compared to the RCTS, the literature on this intervention is controversial and lacking evidence of clear benefits for CP patients.

1.8.2. High Intensity Interval training (HIIT) / High Intensity Circuit Training (HICT)

This study investigates high intensity circuit training, a specific form of high intensity interval training, which requires the participants to perform high velocity exercises within a set of strictly predefined intervals.

There is reason to believe that training velocity rather than maximum strength might be more appropriate for children with cerebral palsy. Medium-intensity training like PRT focuses on improving strength and endurance; strength is usually evaluated based on maximum contraction¹. However, it typically takes over 300ms in most muscles to reach a maximum contraction and many activities of daily living involve fast limb movements with contraction times of 50-200ms^{1,73}. This rapid generation of force is 70% reduced in children with cerebral palsy compared to normally developed peers. Therefore, time-dependent measurements like rapid force development might be more clinically relevant for children with CP¹. Insufficient rapid force development might be the main restricting factor for walking because functional activities of daily living (such as walking) do not necessarily require maximum strength but rather fast muscle contraction (e.g. quadriceps during loading response). In addition to walking, rapid force development is an even better predictor of high-level activities like running and sports (it was better at predicting the “Sports and physical functioning” component of the PODCI questionnaire compared to maximum muscle strength)⁷⁴.

Early rapid force development cannot be influenced by medium-intensity intervention (e.g. PRT), it can be only improved through training at high velocities (e.g. HIIT / HICT). Hence, there is also a need for interventions focused on the ability to produce rapid movements rather than just high levels of force¹.

High intensity interval training (HIIT), defined as “brief intervals of vigorous activity dispersed with periods of low activity or rest,”⁷⁵ is a strengthening intervention focused on rapid movements. High intensity interval training reaches 80-95% of peak oxygen consumption or >90% of the age-related maximum heart rate⁷⁵. The peak intervals last between 1 and 4 minutes and the whole training usually lasts around 20 minutes, which is shorter than similar exercise programs at medium intensity⁷⁵. Figure 8 presents the principle of HIIT compared to traditional training (moderate intensity aerobic continuous training)⁷⁶.

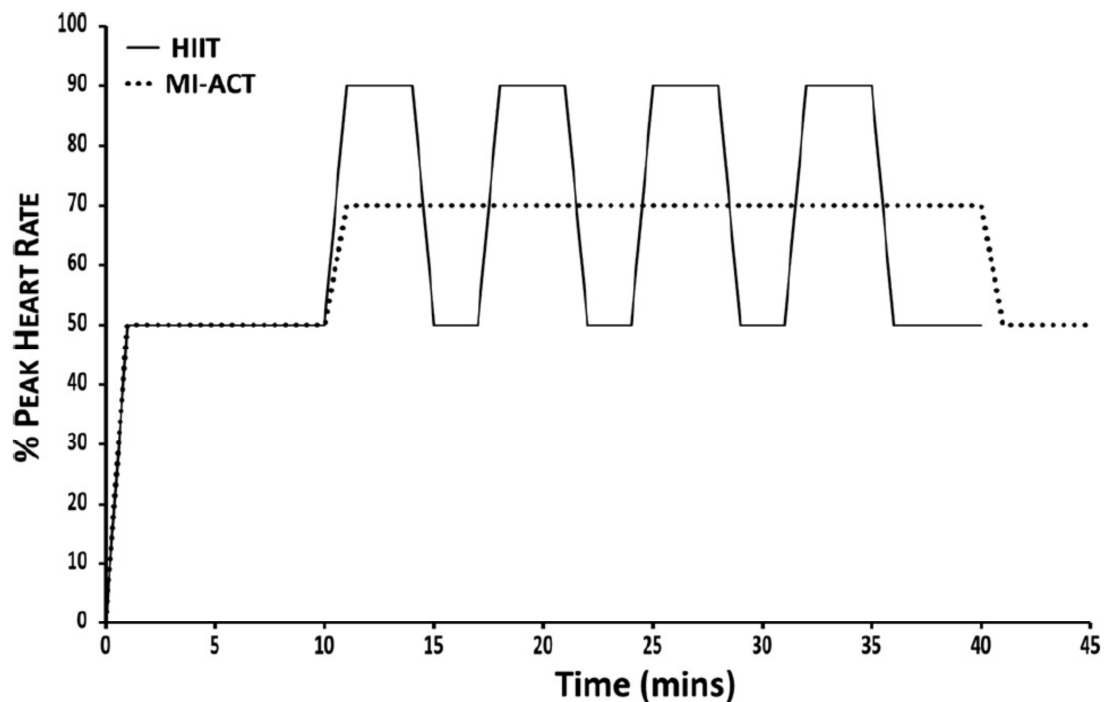


Figure 8: The respective heart rates of a high intensity interval training and a traditional training (moderate intensity aerobic continuous training) during one training sessions. (this figure was reproduced from an article with open access under the following citation⁷⁶)

High intensity interval training has long been used by professional and recreational athletes and leads to improved training effects⁷⁷. HIIT demands the activation of a larger number of motor units with increased recruitment of fast oxidative and glycolytic muscle fibers, increased intensity of muscular biochemical processes, and increased neuromuscular engagement (primarily in the hamstrings)⁷⁸. Furthermore, it has proven to increase VO_{2max} , induce changes in plasma volume, adapt hormonal and metabolic responses, and increase the skeletal muscle oxidative capacities⁷⁹

High intensity interval training is already used successfully in treating many other pathologies. In patients with cardiovascular diseases it provides a stronger stimulus to the cardiovascular system compared to moderate intensity training, resulting in increased myocardial improvements⁸⁰. It is also successfully applied in patients with diabetes, improving multiple parameters of glycemic control, body mass, and adiposity (although the comparison to other exercise programs needs to be further investigated)⁸¹. Additionally, HIIT is also used extensively in treating pulmonary diseases, where it is as least as effective as medium intensity training at improving functional capacity and quality of life. It has the additional benefit of inducing peripheral muscle changes, resulting in fewer negative training

symptoms such as lower dyspnea or leg discomfort⁸⁰. HIIT also improves cognitive functions and can be used in the treatment of attention deficit disorder^{82,83}. It even benefits ophthalmic health where it is used successfully to increase ocular perfusion⁸⁴.

These results make HIIT particularly interesting for children with cerebral palsy. To the best of my knowledge there has been only one study that investigated high intensity training as it pertains to cerebral palsy. Conducted by Lauglo et al.,⁸⁵ the study investigated the VO_{2max} adaptations of a single group of twenty children. They performed 24 individualized sessions at intervals between 1.5 and 4 minutes on a treadmill with a total exercise time of 16 minutes at a heart rate of $>85\%$. VO_{2peak} improved by 10% and $VO_{2submax}$ did not change, which means that the percentage oxygen utilization was reduced. They were also able to show improvements to the children's quality of life as reported by parents⁸⁵.

High intensity circuit training is a specific form of HIIT. While other high intensity trainings include exercises such as cycling, walking, and running, high intensity circuit training incorporates multiple functional exercises into a circuit⁷⁵. The functional exercises within a high intensity circuit training are more likely to improve activities of daily living compared to training on an ergometer, because training for children with cerebral palsy needs to be goal-specific. HICT has shown similar benefits in other population (improving strength, quality of life and peak oxygen uptake)but this is the first study investigating high intensity circuit in children with cerebral palsy⁸⁶.

1.9. International Classification of Functioning, Disability and Health (ICF)

According to the WHO definition, health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity. As health itself is multidimensional, a successful therapeutic intervention (e.g. strength training) should not only improve one outcome measure but also other aspects of a child's health, such as performance in activities and participation in daily life. The different dimensions of improvement can be organized and documented through the ICF.

The ICF offers researchers and clinicians a useful framework to assess multiple domains of health. ICF includes three main components: the body structure and function component (e.g. muscle length, range of motion), the activity component (e.g. running, walking) and the participation component (e.g. a participation questionnaire)⁸⁷. Additionally, the ICF also provides two different context factors; the environmental factors (physical, social, and attitudinal environment of the children) and the personal factors (individual differences).

Previous research on PRT for children with CP evaluated multiple ICF-components and found improvement in the body structure and function component but no effect for activity or participation^{62,63}. For HICT, previous literature shows a positive effect on multiple components but no study has investigated the effect of HICT on all components of the ICF^{88,89}. This study was the first study that investigated all ICF-components for HICT.

Each outcome measure of the present study can be assigned to a component of the ICF. A study that investigates a wide variety of different outcome parameters from multiple ICF-components provides a broader evaluation of the children's health, which facilitates interpretation and application of the results. Therefore, this thesis is structured based on the components of the ICF. Methods, results, and discussion always present first the "body structure and function" component, followed by the activity and the participation components.

1.10. Home-based training

The exercise programs in this study were home-based. Effective training intervention for children with cerebral palsy needs to be specific to the training goal, a common phrase in this field is "you gain what you train"⁹⁰. Practicing an activity at home within the daily routine, surrounded by family and friends, allows the children to better integrate this activity into their daily lives compared to practicing the same activity at a hospital.

Home-based training is one of few interventions for cerebral palsy effective at improving activity and participation⁹⁰. While most home-based training programs are targeted to the activity level, the success is based to a large degree on context factors which are closely related to participation.

Existing research investigated home-based programs for children with cerebral palsy in a wide variety of contexts. These studies included treadmill training, telemetric control, virtual reality, robotic assistance, interactive through the internet, and more⁹¹⁻⁹⁶. One study directly compared a home-based intervention to the same intervention in a laboratory setting and found no difference in effectiveness⁹⁵. However high-quality research on home-based training for strengthening in particular is not yet available. Some of the very first studies on strengthening used home-based training, but recent research has focused exclusively on institutional training^{58,97}. This was the first study to provide a proper analysis of home-based strengthening in populations of children with CP.

Home-based strengthening is also beneficial to health care providers because of its reduced cost. The average cost of a patient with cerebral palsy is estimated around \$921,000 in the United States per individual (20% medical and non-medical direct costs, 80% indirect costs e.g. loss of productivity)⁹⁸. Because of this incredible cost, it can be challenging to fund additional therapy. Home-based training is a cost-effective intervention compared to gym-based institutional training⁹⁹. A study comparing the two interventions for adults with chronic health conditions showed that telephone supported home-based training was over 60% cheaper compared to standard institutional intervention⁹⁹. Further developments in home-based training might bring down cost even more, such as the elimination of hands-on staff involvement).

1.11. Aim and hypotheses

The aim of this randomized, stratified pilot study was to compare two home-based strength training interventions—Progressive Resistance Training (PRT) and High Intensity Circuit Training (HICT)—in children with cerebral palsy. The effect of both training programs on muscle strength, gait, aerobic and anaerobic capacity, and participation was evaluated for this comparison. The null hypothesis was that the effect of HICT and PRT training would be the same in children with cerebral palsy. The alternative hypothesis was that the effect of HICT and PRT training would be different in children with cerebral palsy.

1.12. Potential impact

The research on HICT in other populations has shown that it can have the same benefits as aerobic training but additional anaerobic benefits. Another impact of implementing HICT-training for children with CP is the short training time required. Children and their parents have a limited amount of time and energy to devote to the various complex aspects of the treatment of cerebral palsy⁴². Lack of motivation to participate in community sports or additional therapy can limit therapy compliance. A therapy program that can achieve improvements with a short time investment without leaving the home environment would be very attractive for these families. This might result in higher compliance, motivation, and better outcomes.

Another key aspect of this study is that it was designed as a home-based intervention. This type of training complements institutional training and provides additional intervention during periods without physiotherapy. In certain instances, home-based training might be even more beneficial compared to institutional training because of the optimized context factors.

2. Methods

2.1. Study design

This study is a randomized prospective design that investigated the effects of two different strengthening programs. It was designed as a pilot study because a sample size calculation was not possible.

Participants were evaluated on four separate occasions: T0 - control measurement 8 weeks before the intervention, T1 – baseline measurement before the intervention, T2 - post intervention measurement, and finally at the follow up 16 weeks after the intervention¹. This timeline is presented in Figure 7¹.

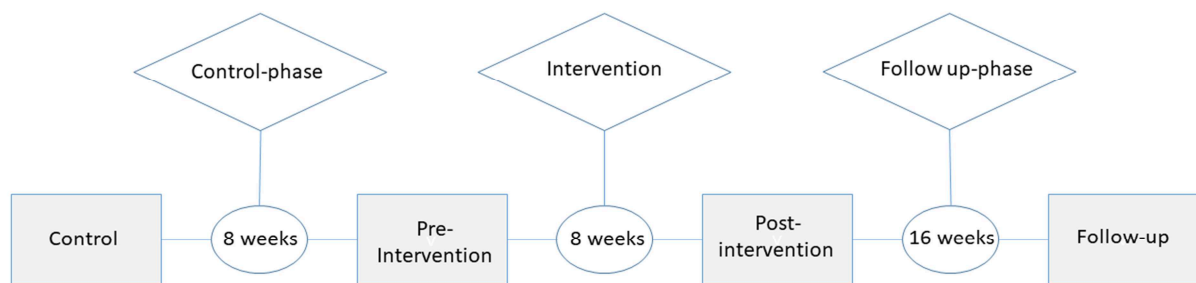


Figure 7: Timeline of the study, (this figure was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)

2.2. Setting

The measurements took place in the gait laboratory of the pediatric orthopedic unit of the Medical University of Graz, in Austria.

2.3. Sample size calculation

There was no previous research on high-intensity training for children with cerebral palsy using these outcome measures. As a result, it was impossible to provide a a-priori sample size calculation.

2.4. Inclusion criteria

- Ambulatory children with unilateral or bilateral spastic cerebral palsy
- Age between 8-16 years
- Ability to accept and follow verbal instructions
- Gross Motor Function Classification System (GMFCS)¹³ at level I-II,
- Willingness to participate

2.5. Exclusion criteria

- Other than spastic forms of cerebral palsy (ataxic, athetoid, or dystonic)
- Quadriplegia
- History of orthopaedic surgery in the previous 12 months
- History of Botulinum Toxin A application in the previous 6 months
- Severe mental retardation

2.6. Ethical approval and consent

The local ethics committee approved this study with the ID EK21-362 ex 09/10 and all participating children and their parents provided informed consent. There were separate consent forms for children between 8 and 12 years of age and teenagers between 12 and 16 years of age, written in age-appropriate language.

2.7. Randomization

A randomized block design was used for the randomization procedure. The intervention was drawn from a sealed container and placed in envelopes. Children were then sequentially assigned to an envelope after baseline testing.

2.8. Recruitment

The main source for recruitment was the outpatient clinic of the local hospital where clinicians screened for children who fit the inclusion criteria¹. Those children received a short introduction to the study, its purpose, and requirements. If parents and children declared initial interest, they were referred to the study personnel who provided additional information and an appointment for the first study visit.

Multiple additional methods of recruitment were implemented to assist the local hospital, including the national physiotherapist association, “Kid’s Chance” in Bad Radkersburg, the Mosaik clinic in Graz, and the clinical gait lab in Speising, Vienna.

2.9. Outcome measures

This study employed outcome measures of all components of the International Classification of Functioning, Disability and Health (ICF). Detailed background information on most outcome measures was provided in the supplemental materials. For more information on the ICF please refer to the Introduction, chapter 1.9. An overview of outcome measures and how they relate to the ICF-model is presented in Figure 8.

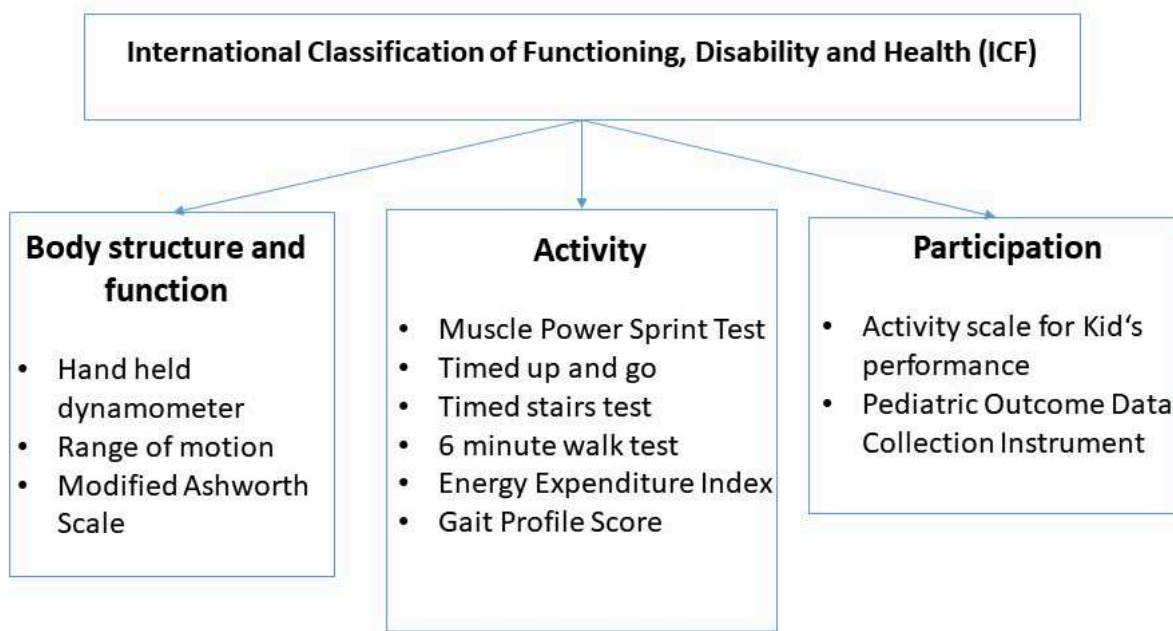


Figure 8: Outcome measures

2.9.1. Body structure and function

2.9.1.1. Muscle strength

Strength was measured using the handheld dynamometer (MicroFET2 by Hogan Health Industries). This study used the “make”-test, in which the examiner holds the HHD stable without any counter force and the child pushes against the HHD with maximum effort¹⁰⁰. Data was captured by two examiners. One examiner operated the hand-held dynamometer and another examiner focused on optimal stabilization of the child to enable consistent isolation of the targeted muscle group. Children were measured in two trials in immediate succession and the average value of both trials was used for evaluation. If a child was unable to produce an isolated force towards the hand-held dynamometer in both trials the measurement for that muscle group was marked as invalid. Instructions and position of the child were standardized. The standardized positions can be found in the supplemental material table 1.

Both legs were evaluated for all patients regardless of involvement. However, only the neurologically more involved leg (per the Modified Ashworth Scale), was used for data analysis. The data analysis used normalization to weight to allow for a sound comparison among participants. Total muscle strength was used to allow for a clinically meaningful evaluation of overall muscle strength. The average Newton/kg value of each muscle group was totaled to create the value.

2.9.1.2. Range of motion

For the range of motion evaluation, children were placed in a neutral supine position. Two examiners measured hip flexion, abduction, adduction, knee flexion, knee extension, ankle dorsal flexion with 0° knee flexion, and dorsal extension with 90° knee flexion. Internal and external hip rotation were measured with hips and knees flexed at 90°. Only hip extension was measured in a neutral prone position.

2.9.1.3. Spasticity

Spasticity was measured using the Modified Ashworth Scale¹⁰¹ (for more information please refer to the chapter, “Spasticity,” in the Introduction).

Quadriceps spasticity was measured in a neutral prone position, calf spasticity in a neutral supine position, and hamstring spasticity in a supine position with the hip flexed at 90° and the contra-lateral leg in full knee flexion. For data analyses a value of “1+” was converted to 1.5.

2.9.2. Activity

2.9.2.1. Muscle Power Sprint test

Anaerobic performance was measured using the Muscle Power Sprint test. The children were instructed to complete six 15-meter runs at maximum pace and not to reduce pace until they crossed the opposite line. The distance was marked with a line on the floor and two cones on each side. Between the runs they had a ten-second rest. This test was performed with two examiners to ensure the most accurate sprint time, with one examiner observing one of the two start/finish lines.

The average time captured between the two assessors was used for evaluation. In case of differences larger than 500ms, data analysis used the time of the assessor who was closer to the relevant line. If one assessor was unsure about the accuracy of his result the time captured by the other assessor was used. The time of completion was then used to calculate the mean power and maximum power of the six runs. This study also calculated an additional parameter that is not part of the standardized test for further interpretations, minimum muscle power which represents the power of the slowest sprint.

2.9.2.2. Six-minute walk test

The six-minute walk test was performed in a 30-meter hallway with a slight bend. A cone was positioned at each end, which served as a turning point for the children. Each meter was marked on the ground. Instructions to the children were standardized: children were instructed

to walk at a normal pace and not hurry. The position of each child after six minutes was marked on the floor; the absolute distance was then calculated and used for data analyses.

2.9.2.3. Energy Expenditure Index

The Energy Expenditure Index was measured and calculated to get an impression of the energy utilization of the children. For this parameter the heart rate of each child was measured at rest and during the six-minute walk test and the EEI calculated for all participants.

2.9.2.4. Timed stairs test

The timed stairs test was adapted to the available setting. The available set of stairs had 10 steps and a railing on both sides; the height of each step was 19.5cm. Due to the width of the stairs it was only possible for children to use one handrail. Children were allowed to use any technique they wanted to climb the stairs; one step at a time with both feet, alternating feet, or skipping steps. It was also up to the child to decide on the starting foot and if they wanted to use a handrail or not. All participants faced forward toward the direction of movement during the test (not to the side).

The children were told to walk up the stairs, quickly but safely, turn around on the top step and come down again until both feet were at the starting step again. Time was started when they received the start signal “go” and stopped when both feet were back at the starting step. The security of the children walking the stairs was monitored and the trial canceled if there was any perceived danger. The child was then instructed how to walk the stairs more safely.

2.9.2.5. Timed up-and-go test

For the timed up-and-go test the children were seated at a stable seat with a back, with feet flat on the floor so that hip and knee were at 90° flexion. The chair was placed three meters away from a point where the color of the floor transitions from black to white. The children had to stand up, walk until both feet were across the point where the floor transitions in color, turn around, walk back to the chair, and sit down. They were told not use their hands when sitting down or standing up, not to rush, and to walk at a leisurely pace.

2.9.2.6. Gait analysis

Gait analysis was captured using ten MX cameras with four ATMI force plates and Vicon workstation. At least 14 trials, with 7 trials on each side for each patient using the Plug-in Gait model were captured. Pelvic, hip, knee, and ankle kinematics, kinetic parameters of the hip, knee and ankle joints, as well as time-distance parameters (gait velocity, cadence, stride length, single and double support time), were used as outcome measures in the study. This

study used the Gait Profile Score, which measures the root mean square difference between the patient's kinematic graph and the average graph of the typical developed population over time, for all planes of pelvis and hip, the sagittal plane of knee and ankle, and for the foot progression angle¹⁰².

2.9.3. Participation

2.9.3.1. *Activity scale for kids' performance version*

A proper evaluation should not only focus on strength or activity measurements in a hospital setting.; it is also essential to measure the impact of the intervention on the daily lives of the children and capture the participation component of the ICF. The ASKp is a questionnaire that asks the children about how much support they needed for a wide range of activities for the last week at home before the measurement. The questionnaire was checked for completeness, screened for potential misinterpretation, and discussed with the children as necessary. Prior to this study no German version of the questionnaire existed, so it was translated in its entirety with a back translation and feedback from the creator of the questionnaire to ensure that the translation was indeed testing the same skills as the English original

2.9.3.2. *PODCI*

The PODCI questionnaire evaluates the performance of the children in daily activities at home, as viewed and completed by their parents. Not all sub-elements were clinically relevant for this study because they were not targeted by intervention (for example, the upper extremity section). As a result, this study analyzed not only the overall score but also sub-scores of each section.

2.10. Statistics

Descriptive statistics were used to provide an overview of the data. The distribution of each dataset was investigated using the residuals and the Shapiro-Wilk test. A two-way repeated measures ANOVA was used if all assumptions were met. Post-hoc tests provided effect size and observed power. Non-normal distributed data was first evaluated with a Friedman test followed by a Wilcoxon signed ranked test¹. A paired t-test was used to compare the difference in improvement between both intervention groups for clinical and functional tests. It was not possible to employ a single statistic test to compare the improvement of the two groups against each other for the whole study that also included mechano-morphologic muscle parameters measured through ultrasound images because of the limited sample size. A

Pearson correlation was employed to investigate the relationship between outcome measures and basic characteristics.

2.11. Intervention

Both intervention groups conducted a circuit training with the identical five functional exercises (see Figure 3). These exercises covered all important muscle groups of the lower extremities (hip extensors, flexors, abductors and adductors, knee extensors and flexors, as well as dorsiflexors and plantar flexors). Children performed three trainings sessions each week with at least one day off in between. There were no additional rules about the setting of the exercise programs, required dress code, time of the day, or location.

2.11.1. Assistance during home intervention

Every patient was given a detailed manual with multiple instructional illustrations. Furthermore, each family received a DVD with instructions for each exercise. Parents were encouraged to call the hospital if there were any difficulties interpreting the instructions or with performing a particular exercise.

2.11.2. Instructions

The children received an initial overview of the exercise program during the first control measurement (T0), which explained how each program worked and the main exercises involved. This main instruction took place at the end of the morning session during the preintervention measurement (T1). During this instruction the parents and their children were once again introduced to the general instructions and rules and the warm up and the cool down exercises. Each exercise was introduced and practiced at a slow pace with sufficient time for questions, explanations, and corrections. This slow round was followed by one or two rounds of the circuit training at the intended normal tempo.

2.11.3. Warm up and cool down period

The warm up exercises consisted of several low activity exercises and a hamstring stretching exercise. The cool down exercises focused on multiple stretching exercises and two low-activity exercises. Both warm up and cool down periods were designed to last about 5 minutes each.

2.11.4. Control of exercises and progress

There were multiple methods used to control and ensure that the children and parents performed the exercises at home correctly: Children were called after one week in order to allow for any questions to be addressed. During this phone call it was possible to go through the exercise program together and discuss any concerns or necessary adaptations. If there were any remaining issues, questions, or uncertainties after the call, the option for children to perform one of their training sessions at the hospital was offered. All training sessions and problems were recorded in a training diary that was collected after the conclusion of the program¹.

2.11.5. Progressive Resistance Training

Progressive Resistance Training (PRT), aimed at strengthening the muscle through progressive overload, is the golden standard for strengthening in children with cerebral palsy. For additional information on the background of and the research on PRT, please refer to chapter 1.8.1 in the Introduction.

For PRT portion of the program the children had to complete 10-12 repetitions of each exercise in three consecutive rounds with an individualized load. Only correct executions were counted by the parents. If they managed to perform 12 (or more) repetitions at three consecutive training sessions for a specific exercise, weight was progressively increased based on the weight of the child.

The individualized load was determined using the 10 repetitions max test at the beginning of the study¹. During the test the children were instructed to perform as many repetitions as possible. If the number of repetitions exceeded 10, weight was added to the vest. If the number of repetitions was less than 10, weight was removed from the vest. This process was repeated until each child had the appropriate weight on the vest that allowed them to do exactly 10 repetitions.

For the progressive resistance group in this study, progressive overload was achieved using a weight vest sold by D&S Vertriebs GmbH. The vest had a total weight of 10kg, with removable bags of 500g each. The weight vest is shown in Figure 9.



Figure 9: Weight vest




2.11.6. High Intensity Circuit Training (HICT)


For the HICT portion of the study exercises were performed within 30 seconds of maximum intensity followed by 30 seconds of rest. All five exercises were performed in the same manner and the cycle was repeated three times with a 90-second break between cycles. Children were asked to perform the maximum possible repetitions within the given timeframe while maintaining the necessary quality of each exercise (e.g. starting and end position reached, stable knee axis). For the next training sessions, the children tried to attain at least two additional repetitions compared to prior results.

2.12. Exercises

Both interventions used the same five exercises, a description of which can be found in Table 1. A more extensive description can be found in the supplemental materials.

Main exercises			
Exercise	Properties	Specific instructions	Final position
Adepted sit to stand	<ul style="list-style-type: none"> • 10-12 repetitions • 3 sets • Load determined by 10 repetition maximum test 	<ul style="list-style-type: none"> • Lower down as if sitting down • Move slowly and in a controlled manner • Stand up after lightly touching the chair (without putting any actual weight on the chair) • Focus on correct leg axis 	

<p>Heel Rises</p>	<ul style="list-style-type: none"> • 10-12 repetitions • 3 sets • Load determined by 10 repetition maximum test 	<ul style="list-style-type: none"> • Knees extended • Lift heels as high as possible • Lower heels as slowly as possible • Don't put weight on the heels, only lightly touch the floor before raising the heels again 	
<p>Lunges</p>	<ul style="list-style-type: none"> • 10-12 repetitions • 3 sets • Load determined by 10 repetition maximum test 	<ul style="list-style-type: none"> • Take a big step forward with one leg • Bend other knee as close as possible to the floor without touching it • Straight upper body • Perform exercise for the other side (switching legs) 	
<p>Bridging</p>	<ul style="list-style-type: none"> • 10-12 repetitions • 3 sets • Load determined by 10 repetition maximum test 	<ul style="list-style-type: none"> • Hips in neutral position throughout the whole exercise • Alternate lifting each foot slightly off the floor 	

<p>Lateral Step ups</p>	<ul style="list-style-type: none"> • 10-12 repetitions • 3 sets • Load determined by 10 repetition maximum test 	<ul style="list-style-type: none"> • Start with both legs on the step board • Move one foot down toward as though stepping down but only slightly touching the floor before bringing it back up on the step board • Perform the same exercise for other foot 	 <p>The image shows a woman in a blue tank top and black leggings performing a lateral step up. She is standing on a grey step board with her right foot on the board and her left foot on the floor. Her body is slightly forward, and she appears to be in the middle of a step-down or step-up motion.</p>
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3. Results

Twenty-eight children participated in this study between April 2015 and July 2017¹. Of those participants, one dropped out during the control phase¹. The remaining twenty-seven children were randomized to one of the interventions (PRT or HICT). An additional five participants dropped out during the interventions¹. Randomization assigned one of them to the progressive resistance program and four to the high intensity circuit program¹. The reason for all dropouts was lack of motivation (affecting 4 children) or a lack of time (affecting 2 children) by either a parent or the child¹. A flowchart depicting the study is presented in Figure 10¹.

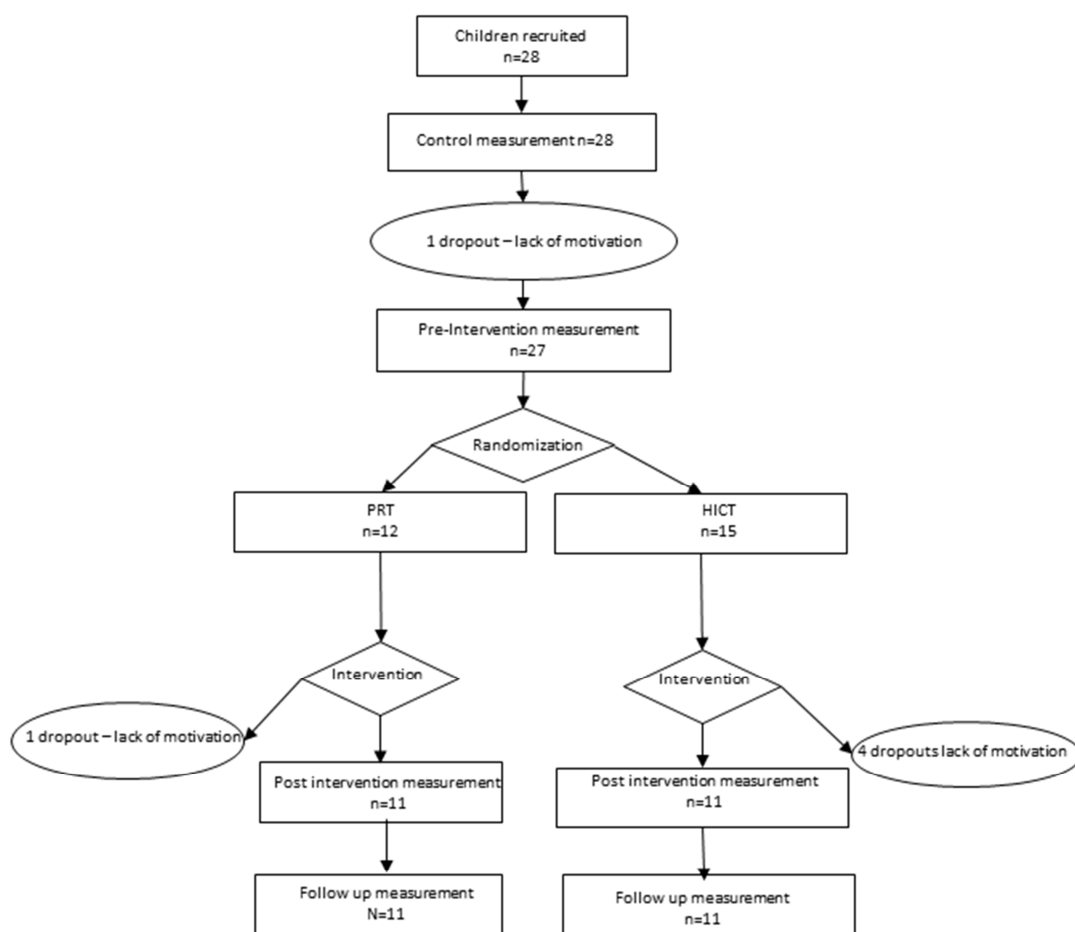


Figure 10: Flowchart of participants in study (this figure was reproduced from the article by Schranz et al.¹ and is covered by the licensing agreement of the article).

Twenty-two children completed the study (11 in each group). However, only 20 children completed the exercise diary (ten in each group)¹. The diaries indicated that the children in the PRT group completed, on average, 86% of all trainings sessions while the HICT-group

completed 88%¹. The average duration of a training session was 40 minutes in the PRT-group while the HICT-group needed only 28 minutes, or 30% less training time¹.

The baseline characteristics of all 22 participants can be found in Table 2¹. There are some slight difference of function (GMFCS), height, and weight, but none of these differences were significant.

Table 2: Basic characteristics of participants at baseline (SD)

Parameter	PRT	HICT
Mean age (years)	12.2 (2.7)	13.4 (2.4)
Sex: male/female	8/3	7/4
GMFCS: I/II	8/3	11/0
Involvement: uni/bilateral	3/8	5/6
Mean height (cm)	145.8 (18.0)	156.4 (15.2)
Mean weight (kg)	38.5 (16.4)	49.4 (14.6)

SD=Standard Deviation, GMFCS=Gross Motor Function Classification System (This table was reproduced from the article by Schranz et al.¹ and is covered by the licensing agreement of the article).

3.1. Strength

At the body structure and function ICF-level both groups improved their total isometric strength, but only the improvement in the HICT-group was significant, with 5.04 N/kg (19.6%, $p=0.02$)¹. Looking at individual muscle groups, the HICT-group achieved significant improvements in their hip extensors, hip abductors, knee flexors, and plantar flexors while there was no significant improvement in any muscle group for the PRT-group¹. Results for individual muscle groups can be found in Table 3 on the next page¹.

Table 3: Summary of all hand-held dynamometers for all muscle groups in N/kg

Outcome Parameter	Values at measurement points as mean				Diff (%)	
	T1		T2		T1-T2	T1-T2
	PRT	HICT	PRT	HICT	PRT	HICT
Hip extensors	4,58	4,48	5,09	5,31	11,1	18,6*
Hip flexors	2,81*	2,84	3,18	2,89	13,3	1,9
Hip abductors	2,93	2,94	3,18	3,60*	8,4	22,3*
Hip adductors	3,23	3,16	3,25	3,55	0,5	12,6
Knee extensors	4,68	3,88	4,98	4,55	6,5	17,4
Knee flexors	2,55	2,15	2,67	2,88*	4,7	33,6*
Dorsal extensors	2,03	1,80	2,18	1,89	7,3	5,1
Plantar flexors	5,01	4,32	4,79	5,81*	4,4	34,6*

PRT, Progressive Resistance Training; HICT, High intensity Circuit Training; Diff, Difference between T1 and T2; * $p < 0.05$; ** $p < 0.01$

(This table was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)

3.2. Activity / participation results

We observed improvements at the ICF activity level: the PRT-group improved their timed up-and-go test (11.7%, $p=0.05$) and timed stairs test (14.3%, $p=0.003$)¹. However, the HICT group achieved better results in the Muscle Power Sprint test (mean muscle power $p=0.001$ / maximum muscle power $p=0.004$)¹. Other measures of mobility or activity did not change¹.

At the ICF participation level, only the ASKp-Score in the PRT-group showed a trend toward improvement ($p=0.051$)¹.

In the follow-up period, mean muscle power ($p=0.05$) and total isometric strength ($p=0.03$) decreased significantly for the HICT-group, other outcome measures did not change¹. There were no changes in control or follow-up period for the PRT-group¹.

The results of all outcome measures for the PRT-group can be found in Table 4 and those for the HICT group in Table 5. A direct comparison of both results can be found in Table 6, starting on the next page.

Table 4: Summary of outcome measures for the PRT group (standard deviation)

Outcome Parameter	Values at measurement points as mean (CI)				p-Values			
	T0	T1	T2	T3	T0-T1	T1-2	T2-T3	Diff (%)
Total isometric strength (N/kg)	26.0 (8.0)	27.9 (7.4)	28.9 (7.4)	29.3 (7.0)	0.272	0.569	0.815	3.6
Muscle Power Sprint test Mean (PWR)	100.1 (81.8)	95.6 (75.8)	102.7 (73.5)	112.4 (95.1)	0.736	0.148	0.44	7.4
Muscle Power Sprint test Max (PWR)	121.2 (99.3)	119.8 (93.3)	122.4 (85.3)	129.5 (104.2)	0.942	0.877	0.672	2.2
Muscle Power Sprint test Min (PWR)	77.4 (65.2)	75.1 (60.9)	89.2** (65.8)	89.5 (81.7)	0.722	0.003	0.722	18.9
Timed up-and-go test (seconds)	9.8 (1.7)	10.3 (4.2)	9.1* (2.1)	8.5 (1.9)	0.79	0.05	0.182	11.7
Timed stairs test (seconds)	12.7 (3.6)	12.6 (3.8)	10.8** (4.0)	11.9 (6.3)	0.894	0.003	0.657	14.3
6 minute walk test (meters)	500.1 (50.2)	514.2 (55.9)	518.8 (48.0)	496.3 (65)	0.207	0.582	0.188	1.0
Energy expenditure index (Score)	0.69 (0.32)	0.77 (0.2)	0.64 (0.3)	0.72 (0.2)	0.403	0.191	0.421	16.9
GPS (°)	9.8 (3.1)	8.8 (3.3)	9.2 (3.4)	8.7 (3.7)	0.278	0.663	0.542	-4.5
ASK (Score)	88.4 (11.8)	85.8 (14.6)	90.1 (12.9)	89.3 (13.1)	0.214	0.051	0.6	5.0
PODCI (Score)	73.1 (18.2)	78.5 (17.2)	81.3 (14.8)	82.1 (14.0)	0.169	0.241	0.169	3.6

*PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; *p<0.05; ** p<0.01*

Table 5: Summary of outcome measures for the HICT group (standard deviation)

Outcome Parameter	Values at measurement points as mean (CI)				p-Values			
	T0	T1	T2	T3	T0-T1	T1-2	T2-T3	Diff (%)
Total isometric strength (N/kg)	26.5 (5.7)	25.7 (8.4)	30.7** (3.3)	27.2 * (7.1)	0.559	0.017	0.034	5.3
Muscle Power Sprint test Mean (PWR)	211.3 (139.5)	191.6 (121.5)	239.1** (152.8)	212.9* (166.4)	0.148	0	0.046	13.0
Muscle Power Sprint test Max (PWR)	264.2 (170.9)	226.2 (134.1)	280.1** (177.7)	264.8 (214.0)	0.058	0.004	0.366	6.8
Muscle Power Sprint test Min (PWR)	150.4 (129.2)	152.2 (118.7)	187.5** (143.5)	166.6 (133.7)	0.859	0.003	0.248	25.8
Timed up-and-go test (seconds)	8.1 (0.9)	7.5 (1.3)	7.6 (1.0)	7.6 (1.2)	0.534	0.109	0.929	11.4
Timed stairs test (seconds)	8.2 (2.0)	7.9 (2.3)	7.4 (2.0)	7.7 (2.6)	0.286	0.859	0.79	14.4
6 minute walk test (meters)	549.2 (69.1)	567.5 (64.6)	573.1 (58.1)	561.2 (65.3)	0.107	0.505	0.479	1.0
Energy expenditure index (Score)	0.61 (0.2)	0.59 (0.3)	0.61 (0.2)	0.58 (0.3)	0.853	0.878	0.774	15.5
GPS (°)	8.5 (1.7)	8.8 (3.0)	9.5 (2.8)	8.2 (2.4)	0.725	0.518	0.186	-4.3
ASK (Score)	94.7 (7.5)	90.9 (10.7)	94.0 (10.3)	96.0 (6.7)	0.612	0.161	0.31	5.6
PODCI (Score)	82.8 (12.5)	82.5 (13.4)	88.7 (10.3)	87.8 (15.5)	0.85	0.09	0.80	7.5

*PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; *p<0.05; ** p<0.01*

Table 6: Comparison between groups (standard deviation)

Outcome Parameter	Values at measurement points as mean (SD)								Diff (%)		
	T0		T1		T2		T3		T1-T2	T1-T2	
	Intervention	PRT	HICT	PRT	HICT	PRT	HICT	PRT	HICT	PRT	HICT
Total isometric strength (N/kg)		26.0 (8.0)	26.5 (5.7)	27.9 (7.4)	25.7 (8.4)	28.9 (7.4)	30.7 (3.3)*	29.3 (7.0)	27.2 (7.1)*	3.6	19.6*
Muscle Power Sprint test Mean (PWR)		100.1 (81.8)	211.3 (139.5)	95.61 (75.8)	191.6 (121.5)	102.7 (73.5)	239.1 (152.8)**	112.4 (95.1)	212.9 (166.4)*	7.4	24.8**
Muscle Power Sprint test Max (PWR)		121.2 (99.3)	264.2 (170.9)	119.8 (93.3)	226.2 (134.1)	122.4 (85.3)	280.1 (177.7)**	129.5 (104.2)	264.8 (214.0)	2.2	23.8**
Timed up-and-go Test (seconds)		9.8 (1.7)	8.1 (0.9)	10.3 (4.2)	7.5 (1.3)	9.1 (2.1)*	7.6 (1.0)	8.5 (1.9)	7.6 (1.2)	11.7*	-1.3
Timed stairs test (seconds)		12.7 (3.6)	8.2 (2.0)	12.6 (3.8)	7.9 (2.3)	10.8 (4.0)**	7.4 (2.0)	11.9 (6.3)	7.7 (2.6)	14.3**	6.3
6 minute walk test (meters)		500.1 (50.2)	549.2 (69.1)	514.2 (55.9)	567.5 (64.6)	518.8 (48.0)	573.1 (58.1)	496.3 (65)	561.2 (65.3)	1.0	1.0
Energy Expenditure Index (Score)		0.69 (0.32)	0.61 (0.2)	0.77 (0.2)	0.59 (0.3)	0.64 (0.3)	0.61 (0.2)	0.72 (0.2)	0.58 (0.3)	16.9	-3.4
GPS (°)		9.8 (3.1)	8.5 (1.7)	8.8 (3.3)	8.8 (3.0)	9.2 (3.4)	9.5 (2.8)	8.7 (3.7)	8.2 (2.4)	-4.5	-8.0
ASK (Score)		88.4 (11.8)	94.7 (7.5)	85.8 (14.6)	90.9 (10.7)	90.1 (12.9)	94.0 (10.3)	89.3 (13.1)	96.0 (6.7)	5.0	3.4
PODCI (Score)		73.1 (18.2)	82.8 (12.5)	78.5 (17.2)	82.5 (13.4)	81.3 (14.8)	88.7 (10.4)	82.1 (14.0)	87.8 (15.5)	3.6	7.5

*PRT, Progressive Resistance Training; HICT, High intensity Circuit Training; PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; *p<0.05; ** p<0.01*

3.3. Difference between groups

Table 7 presents the difference in improvement between the two groups. For the “body structure and function” component of the ICF, the HICT group had a higher improvement in knee flexor and plantar flexor strength¹. While there was a considerable difference in total strength improvement (1 N/kg to 5 N/kg) this difference was not significant. The HICT group had higher functional improvement in the sprint test while the PRT group had a higher improvement in the timed stairs test.

3.4. Compliance

Compliance was evaluated using the training diaries and was fairly similar in both groups. The PRT group completed an average of 86% of training sessions; the HICT group completed 88%¹. Each group included four children who completed all 24 training sessions and one child with a compliance of 50% or lower. All other children had a compliance of 79% or higher.

3.5. Load

Although this study investigated two completely different interventions, it is essential to make assumptions on the load that was performed by each group per training session. The complete weight that each patient lifted for each exercise was calculated (body weight + weight vest). The complete weight relative to body weight was then used for load calculation multiplied by the number of repetitions for each patient and the number of sessions completed. The complete load for each exercise was added together. The result is presented in Table 8.

For additional accuracy, this study also controlled for the differences between exercises. Lifting the same amount of weight in a heel-rises exercise and in a bridging exercise is a completely different challenge. The mean relative improvement for all exercises was calculated but the results were identical (see Table 9): the children in the PRT group trained with 22% lower loads than the children in the HICT group.

Table 7: Absolute Improvement and t-test between groups in (N/kg)			
Exercise	PRT	HICT	p-value
Total Strength (N/kg)	1.03	5.03	0.126
Hip extensors	0.46	0.83	0.424
Hip flexors	0.32	0.05	0.397
Hip abductors	0.16	0.65	0.095
Hip adductors	-0.03	0.44	0.183
Knee extensors	0.27	0.68	0.447
Knee flexors	0.11	0.72	0.023*
Dorsal extensors	0.13	0.09	0.831
Plantar flexors	-0.39	1.68	0.027*
MPST (mean)	7.04	47.55	0.020*
MPST (max)	2.56	53.87	0.038*
MPST (min)	14.17	35.29	0.153
TUGT (seconds)	-1.26	-0.05	0.115
TST (seconds)	-1.83	-0.50	0.006**
6-min walk test (meters)	4.64	5.64	0.933
EEI	-0.13	0.01	0.298
GPS	0.43	0.65	0.880
ASKP	4.26	2.44	0.614
PODCI	2.81	6.58	0.386

*PRT, Progressive Resistance Training; HICT, High intensity Circuit Training; PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; *p<0.05; **p<0.01*

Table 8: Load difference between groups in kg lifted by each group * repetitions and percentage of bodyweight (SD)

Parameter	PRT	HICT	% difference
kg %	25636	32973	22.25

PRT. Progressive Resistance Training; HICT. High Intensity Circuit Training

Table 9: Load of exercises performed in % of bodyweight for each exercise * total repetitions of each exercise with difference between groups

Exercise	PRT	HICT	% difference between groups
Sit to stand	3723	4745	2.5
Heel rises	3757	6164	39.0
Lunges	7419	6382	-16.3
Bridging	3359	6736	50.1
Lateral step ups	7377	8945	17.5
Average difference			22.4

PRT. Progressive Resistance Training; HICT. High intensity Circuit Training

3.6. Muscle Power Sprint test

More detailed information from the Muscle Power Sprint test is provided in tables 10 and 11, which show the average individual sprint times before and after the intervention. Both groups demonstrated faster times in the first sprint. After the intervention, the first sprint showed the smallest improvement. The gains of all other trials were similar. The difference between the fastest and slowest time improved for both groups: from 0.21 to 0.11 seconds in the PRT group and from 0.18 to 0.15 seconds in the HICT group.

Table 10: Average time of each of the six sprints of the Muscle Power Sprint test in sequential order for PRT Group in seconds

Order of Sprint	T1	T2	Diff.
Sprint 1	4.90	4.87	0.04
Sprint 2	5.07	4.81	0.27
Sprint 3	5.26	4.94	0.32
Sprint 4	5.15	4.94	0.21
Sprint 5	5.19	4.83	0.36
Sprint 6	5.21	4.89	0.32

Table 11: Average time of each of the six sprint of the Muscle Power Sprint test in sequential order for HICT group in seconds

Order of Sprint	T1	T2	Diff.
Sprint 1	4.06	3.90	0.16
Sprint 2	4.07	3.75	0.31
Sprint 3	4.16	3.75	0.41
Sprint 4	4.15	3.87	0.28
Sprint 5	4.15	3.88	0.27
Sprint 6	4.24	3.83	0.41

3.7. Gait analysis

The gait profile score and all elements of the movement analysis profile did not change¹⁰². However, there were some kinetic improvements. The HICT group showed more hip abductor moment in the stance phase. While the PRT group was also able to improve maximum abductor moment, this improvement did not persist across the entire stance phase. The relevant kinetic graphs are shown in Figure 11 and Figure 12.

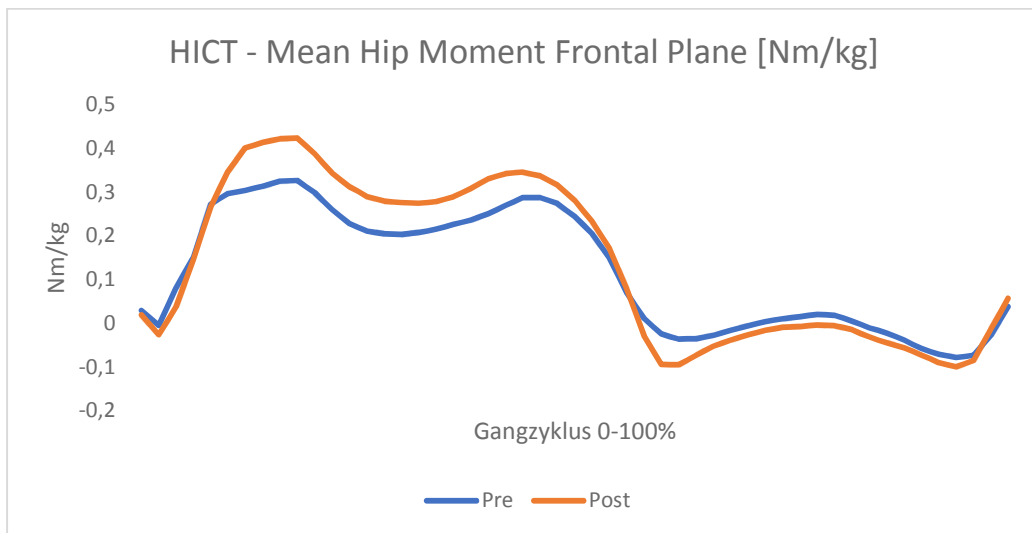


Figure 11: Hip moment during gait in the frontal plane for the HICT group in Nm/kg

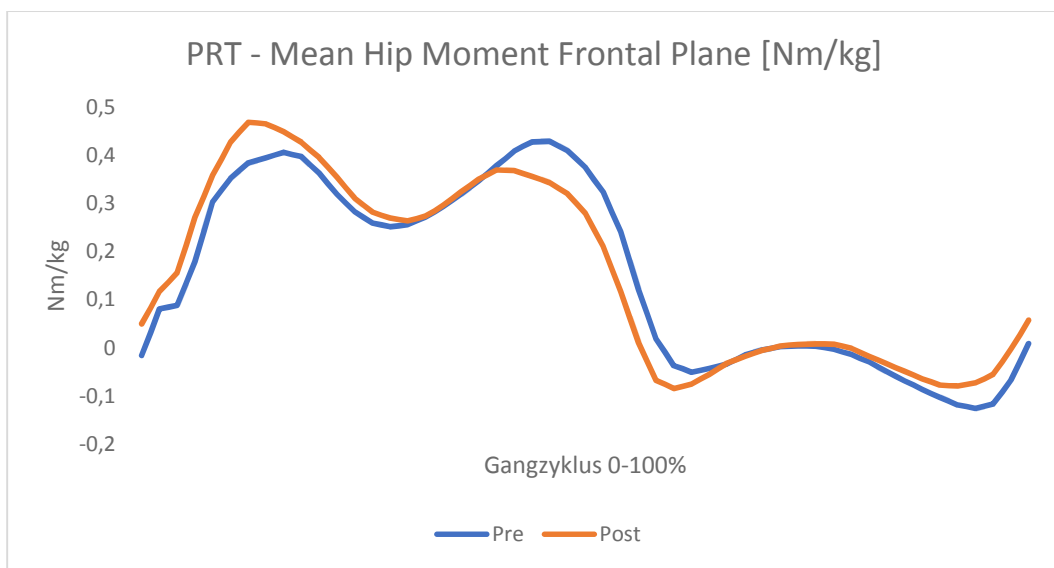


Figure 12: Hip moment during in the frontal plane for the PRT group in Nm/kg

3.8. Summary of individual ASKp and PODCI scores

The participation questionnaires show that several children scored high even before the intervention. For the children's questionnaire (ASKp). 6 of the 22 children had a perfect score (100%) before the intervention. 12 had a score over 95%. and 17 had a score over 80%. In the parent's questionnaire (PODCI). there were 4 children out of 21 with a score over 95%. 11 with a score over 80%. and 19 with a score over 70%.

3.9. PODCI sub-scores

The PODCI questionnaire can be reported not only as an overall score but also as sub-category scores, focusing on specific elements of daily life. While the PRT group did not improve, the HICT group showed significant improvement of the “transfer and mobility” and the “happiness” sections. The results for the PODCI sub-scores are presented in Table 12. The ASKp does not provide sub-scores.

Subscore	Values at measurement points as mean (sd)				p-value	
	T1		T2		T1-T2	T1-T2
	PRT	HICT	PRT	HICT	PRT	HICT
Upper extremities	78.8 (17.5)	80.7 (24.7)	84.9 (10.9)	91.7 (9.6)	0.14	0.07
Transfer and basic mobility	89.3 (12.1)	95.7 (5.9)	90.2 (13.1)	98.0 (3.8)*	0.71	0.04
Sports and physical functioning	70.3 (21.5)	80.1 (12.9)	73.0 (19.1)	85.0 (11.9)	0.37	0.06
Pain / comfort	75.7 (22.6)	73.4 (28.7)	77.2 (23.4)	80.0 (25.2)	0.70	0.50
Happiness	70.5 (24.0)	81.4 (10.5)	74.1 (18.5)	90.0 (7.7)**	0.34	0.01**
Global functioning	78.5 (17.2)	82.5 (13.4)	81.3 (14.8)	88.7 (10.4)	0.25	0.09

*PRT. Progressive Resistance Training; HICT. High intensity Circuit Training. *p<0.05; ** p<0.01 (This table was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)*

3.10. Range of motion

Range of motion was evaluated as a control measurement (see Table 13). None of the values showed any significant relationship between pre- and post-evaluations.

Table 13: Range of motion for both groups at T1 and T2 in degrees (SD)

Outcome Parameter	T1		T2		T1-T2	
	PRT	HICT	PRT	HICT	PRT	HICT
Hip extensors	14.8 (5.3)	15.9 (4.6)	14.6 (3.5)	13.6 (3.6)	0.90	0.23
Hip flexors	125.7 (10.8)	126.1 (10.5)	126.6 (9.3)	129.1 (9.4)	0.72	0.20
Hip abductors	30.9 (8.0)	32.3 (6.0)	29.6 (4.0)	28.2* (3.4)	0.48	0.04*
Hip adductors	13.4 (5.1)	11.4 (3.8)	12.7 (4.7)	12.3 (2.7)	0.88	0.48
Hip external rotation	56.6 (9.4)	43.6 (12.5)	51.4 (10.0)	44.1 (12.9)	0.17	0.90
Hip internal rotation	49.3 (18.7)	43.6 (12.5)	48.0 (16.4)	44.1 (12.9)	0.68	0.89
Knee extensors	7.1 (5.7)	7.5 (4.8)	5.9 (4.9)	6.6 (3.9)	0.13	0.07
Knee flexors	148.2 (5.9)	148.2 (3.9)	147.7 (5.7)	145.9 (4.6)	0.85	0.23
Dorsal extensors 0°	14.8 (7.1)	15.2 (8.3)	13.4 (9.0)	17.7 (6.3)	0.67	0.10
Dorsal extension 90°	25.5 (5.5)	24.6 (8.5)	24.1 (11.1)	24.1 (6.0)	0.64	0.78
Plantar flexors	39.6 (6.6)	39.3 (6.0)	40.2 (9.6)	41.4 (11.7)	0.81	0.41

PRT. Progressive Resistance Training; HICT. High intensity Circuit Training. * $p < 0.05$; ** $p < 0.01$

3.11. Spasticity

The results of the Modified Ashworth Scale for both groups are presented in Table 14. Neither training program had an impact on spasticity.

Table 14: Average spasticity for both groups at T1 and T2 with the Modified Ashworth Scale (SD)

Outcome parameter	Values at measurement points as mean				Diff (%)	
	T1		T2		T1-T2	
Intervention	PRT	HICT	PRT	HICT	PRT	HICT
Gastrocnemius	1.09	0.36	0.88	13.6	0.89	0.50
	(0.70)	(0.50)	(0.67)	(3.6)		
Rectus	0.6	0.18	0.55	0.09	0.86	0.85
	(0.69)	(0.40)	(0.69)	(0.30)		
Quadriceps	0.27	0	0.45	0.18	0.89	0.71
	(0.47)	(0)	(0.52)	(0.40)		

*PRT. Progressive Resistance Training; HICT. High intensity Circuit Training. *p<0.05; **p<0.01;*

3.12. Effect size and observed power

Effect size and observed power were calculated for all significant results using post-hoc tests to examine the validity of any conclusions despite the insufficient sample size. The improvement of Total muscle strength in the HICT group was sufficiently powered (Total strength, hip extensors, hip abductors, knee flexors and plantar flexors). Additionally, the power was also large enough for the HICT improvement of the “Happiness”-sub category for the PODCI-questionnaire. The results are presented in Table 15 on the next page.

Table 15: Effect size of outcome measures which showed a significant change in this study

Exercise	PRT		HICT	
	Effect size	Power	Effect size	Power
Total Strength (N/kg)	0.14	0.16	0.68	0.90
Hip extensors	0.34	0.46	0.72	0.95
Hip abductors	0.14	0.15	0.86	0.99
Knee flexors	0.13	0.14	1.22	1.00
Plantar flexors	0.22	0.26	0.77	0.96
MPST (mean)	0.09	0.11	0.34	0.46
MPST (max)	0.03	0.06	0.34	0.45
MPST (min)	0.22	0.26	0.27	0.33
TUGT (seconds)	0.34	0.46	0.04	0.07
TST (seconds)	0.47	0.69	0.23	0.27
PODCI “Transfer and Mobility”	0.07	0.09	0.44	0.64
PODCI “Happiness”	0.17	0.18	0.91	0.99

PRT, Progressive Resistance Training; HICT, High intensity Circuit Training; PWR, Power; MPST, Muscle Power Sprint test; TUGT, Timed up-and-go test; TST, Timed stairs test; max, maximum; min, minimum

3.13. Correlations

Since children improved functionally, we examined which gain in muscle strength led to this improvement. We also correlated all muscle strength changes with all changes in functional tests.

There were two highly significant correlations ($p < 0.01$) between strength and functional outcome measures, which are presented in Table 16. Children with faster sprint times had larger hip abductor strength improvement and children that scored better in the six-minute walking test had larger knee extensor strength improvement.

While there were several other significant correlations (all below 0.5 Pearson coefficient). the corresponding histograms show no clear relationship. A study with additional patients is needed for a proper analysis of potential correlations to confirm this trend.

There were no highly significant correlations between baseline characteristics and outcome measures and between multiple outcome measures. The tables indicating these additional correlations can be found in the supplemental materials.

Table 16: Correlation between parameters of strength and activity/participation outcome measures: Pearson correlation coefficient (p-value) for differences between T1 and T2

Correlation	Muscle groups (N/kg)								
	TS	HE	HF	HAbd	HAdd	KE	KF	DE	PF
Mean muscle power	0.25 (0.28)	-0.19 (0.40)	-0.22 (0.33)	0.54** (0.01)	0.24 (0.29)	0.11 (0.64)	0.30 (0.17)	-0.09 (0.68)	0.36 (0.11)
Max muscle power	-0.37 (0.10)	-0.25 (0.27)	0.0 (0.99)	0.03 (0.88)	-0.22 (0.32)	-0.28 (0.21)	-0.45 (0.04)	-0.09 (0.70)	-0.34 (0.13)
Min muscle power	0.11 (0.63)	-0.21 (0.35)	-28 (0.20)	0.33 (0.14)	0.20 (0.37)	-0.05 (0.82)	0.37 (0.09)	-0.19 (0.39)	0.21 (0.35)
Timed up-and-go test (seconds)	0.17 (0.46)	0.10 (0.65)	-0.08 (0.72)	0.06 (0.81)	0.12 (0.59)	0.18 (0.43)	0.10 (0.67)	-0.39 (0.07)	0.31 (0.17)
Timed stairs test (seconds)	-0.19 (0.42)	0.09 (0.69)	0.43* (0.05)	-0.13 (0.55)	-0.23 (0.3)	-0.18 (0.42)	0.24 (0.28)	-0.08 (0.74)	-0.02 (0.93)
6-minute walk test (meters)	0.26 (0.25)	0.11 (0.63)	0.30 (0.18)	0.08 (0.73)	0.37 (0.09)	0.56** (0.01)	0.42 (0.05)	0.11 (0.63)	-0.08 (0.73)
Energy expenditure index (score)	0.17 (0.45)	-0.30 (0.17)	0.21 (0.34)	0.15 (0.51)	-0.05 (0.81)	0.31 (0.16)	0.04 (0.87)	0.21 (0.34)	0.24 (0.30)
GPS (°)	-0.05 (0.83)	0.20 (0.38)	-0.04 (0.85)	-0.14 (0.52)	-0.18 (0.41)	-0.12 (0.59)	-0.11 (0.63)	-0.07 (0.76)	0.04 (0.87)
ASKp	0.02 (0.93)	-0.15 (0.50)	0.26 (0.24)	0.21 (0.36)	-0.17 (0.44)	0.26 (0.24)	-0.42 (0.05)	0.18 (0.42)	0.03 (0.89)
PODCI	0.40 (0.08)	-0.29 (0.20)	0.12 (0.62)	0.53* (0.01)	0.29 (0.20)	0.28 (0.21)	0.20 (0.38)	0.15 (0.53)	0.32 (0.17)

*PRT. Progressive Resistance Training; HICT. High intensity Circuit Training ; PWR. Power; GPS. Gait Profile Score; ASKp. Activity Scale for Kids performance Version; PODCI. Pediatric Outcome Data Collection Instrument; Diff. Difference between T1 and T2; *p<0.05; ** p<0.01*

3.14. Complications

A sole patient was evaluated for a painful heel after the training period. He suffered from a minor skin irritation and was instructed to refrain from excessive exercise for three days. There were no other complications as a result of the intervention.

3.15. Missing values

In the HICT group there are two missing values for total muscle strength: two children were not able to selectively activate their dorsal extensors or plantar flexors and were excluded for total muscle strength. In the PRT group there was a missing value for the EEI-measurement because of a defective heartrate monitor; the measure of the control measurement was used instead. Additionally, one child came without parents for a measurement. The parent questionnaire (PODCI) was sent to the parents to be completed the same day but was not completed. As a result, this study excluded the PODCI values for this patient.

4. Discussion

This study investigated two strengthening programs for children with cerebral palsy (CP): Progressive Resistance Training (PRT) and High Intensity Circuit Training (HICT)¹. It is the first study investigating HICT in this population.

The HICT group improved in both strength and activities of daily living and participation. The PRT group showed improvement for some activities (climbing stairs, standing up from a chair, and walking) but did not improve in strength or participation. These larger improvements in the HICT group were achieved even though their exercise session was considerably shorter compared to the PRT group¹.

These results indicate that both exercise programs improve function but HICT looks to be the preferable option for strengthening in children with CP. Since both programs were home-based, the study also indicated the viability of adopting a home-based intervention into traditional institutional training. These encouraging results provide the basis for further research on HICT for CP with an increased sample size.

4.1. ICF body structure and function

At the body structure and function level of ICF only the HICT group improved strength (total muscle strength increased by 20%)¹. These average strength improvements are consistent with similar studies examining high-velocity training, however variability in this study was greater, because of the difference in training setting. In comparison to the study of Van Vulpen, children in this study trained at home and had to follow strict intervals². While this challenged the compliance of the children to produce maximum effort it provided them with the opportunity for even higher improvement due to the increased control. The use of intervals and optimized context factors could explain why in our study the variability of strength improvement was higher (for more information on “context factors” refer to chapter 1.10, for more information on the ICF refer to chapter 1.9.).

A closer investigation of the strength improvement after high-intensity training for individual muscle groups found significant changes for plantar flexors, knee flexors, hip extensors, and hip abductors for participating children¹. These muscles are most important for propulsion and stability in walking and running, which could explain the improvements in some activity tests.

The strength improvement of the PRT group was considerably lower compared to the HICT group (PRT:4% / HICT:20%). Strength gains were also reduced compared to previous PRT-research (8% strength improvement)^{1,3}. This might be due to the reduced sample size and the limitations of home-based training (see 4.10). The higher improvements of the HICT group can be exclusively attributed to differences in the training mode because both groups went through the exact same five exercises and movements.

Although the two strengthening programs followed the same exercises, the modes of training were different¹; both trainings targeted different forms of strength improvement. While PRT is designed to improve maximum strength, HICT focuses on anaerobic power and the rate of force development^{4,5}. This means that a single strength parameter is not suited to evaluate both exercise programs. While the maximum muscle strength that we captured using the hand-held dynamometer is the optimal tool to measure strength improvement after PRT, the optimal measurement for the HICT group is rapid force development, which requires a dynamometer (not feasible in our case)⁶. Instead, we used the Muscle Power Sprint test (MPST), which depends on rapid acceleration and explosive force, and is a good outcome measure for anaerobic power in clinical setting⁷.

4.2. ICF activities

For the different types of activity tests that were performed for this study, children in the PRT group achieved better results in the tests with submaximal continuous load (timed stairs test and the timed up-and-go test) and HICT group performed better in the test that required short bursts of high energy (MPST)¹. This is in line with a common statement in the field “You gain what you train”^{1,8}. To achieve functional improvement, strengthening needs to be task-specific to the desired functional goal of the intervention^{1,9}. In this study, both training programs improved functional outcomes specific to the focus of their exercises¹.

These results contrast to the available literature on PRT that has failed to show activity improvement in children with CP^{3,10}. A possible explanation for this might be that the strengthening programs in this study were specifically targeted at improving activities. A functional training focused on activities of daily living (ADLs) will likely show improvement on the activity level. The children in this study also benefited from the advantages of home-based exercise training, e.g. optimized context factors (refer to chapter 1.10).

Other outcome measures of mobility and activity did not improve (six-minute walk test, Gait Profile Score, Energy Expenditure Index)¹. A reason for this other lack of improvement might be a ceiling effect: many participating children were high-functioning, most of them were classified within the Gross Motor Function Classification System as GMFCS I (e.g. members of basketball teams, daily walkers, or members of a soccer clubs). While these children were challenged by the developed training program and showed improvement among some parameters, there are other outcome measures that evaluated activities with no additional room for improvement. For example, the task of walking five meters at a self-selected speed was already performed close to full potential.

Another explanation for this lack of improvement is that the exercises and outcome measures might not have been targeted to the specific problems of the participating children. Further improvements of their walking ability might depend not on strength but on other aspects like balance, coordination, or endurance¹. Hence, a child's pure strength-training program might not be targeted enough to improve their ability to walk¹.

4.2.1. Muscle Power Sprint test (MPST)

A closer investigation of the individual activity tests shows the first sprint was the fastest for both groups in the MPST with hardly any improvement after the intervention. However, there was considerable improvement of consistency across sprints. Because mean- and maximum-muscle power of the sprint test might not be the best parameters to capture all the actual improvement in children with CP after strength-training, this study provided a third parameter: minimum muscle power. While the PRT group showed no functional improvement as measured by mean and maximum performance in Muscle Power Sprint test, minimum muscle power improved significantly. The HICT group showed the same pattern despite a completely different form of strength-training. This finding might be of particular benefit to strengthening research in children with CP which has failed to find functional improvement. The main functional impact of strengthening in children with CP might be on performance consistency, not maximum performance. For future strengthening research it would be beneficial to develop and employ more outcome parameters that measure performance stability over multiple attempts and not just the best attempt for different types of functional improvement.

4.2.2. Six-minute walk test

Our measure of aerobic performance, the six-minute walking test, did not change for either group¹. This is in contrast to a previous study by Lauglo et. al. which showed significant improvement in aerobic capacity (measured as VO_{2peak}) in children with CP^{1,5}. However, this lack of improved aerobic capacity is not surprising, because the study by Lauglo specifically focused on endurance, while this study used functional exercises instead¹.

4.2.3. Timed stairs test / timed up-and-go test

For both the timed stairs test and timed up-and-go test considering the considerable differences in strength improvement (4% compared to 20%). One possible explanation might be differences in baseline characteristics. For the timed stairs test the PRT group had an average time at the baseline measurement that was more than 50% slower than the HICT group (12s compared to 8s). This means that the children in the PRT group had more room for improvement for this outcome measure. Another explanation is that the training in the PRT group was more specific to medium-intensity PRT, as mentioned at the start of the chapter.

4.2.4. Gait analysis

The results of the gait analysis showed no change for kinematic parameters. Even a closer investigation of the Gait Profile Score using the Movement analysis profile shows not a single parameter that changed. The lack of improvement of the Gait Profile Score is consistent with other strengthening research:¹⁰ exercises designed to improve strength will barely impact the gait pattern. If the goal is kinematic improvement it is necessary to employ exercises that specifically target gait and the motion during gait; strength training alone is not specific enough to allow kinematic improvement. Nevertheless, there was a small improvement of kinetic parameters: hip abduction moment showed clear improvement for the HICT group. Those results are consistent with the strength measurements that showed improvement of muscle groups responsible for stability in the stance phase.

4.2.5. Energy Expenditure Index

The energy expenditure index did not show any improvement. However, because of the lack of validity of this outcome measure, this does not mean necessarily that energy consumption

of the children did not change. Future studies should include spirometry measure to further investigate how HICT impacts energy expenditure.

4.3. ICF measures of participation

The generalized scores gathered from the two participation questionnaires did not improve. It is possible that a ceiling effect influenced these results¹. Several participants entered the study with very high scores¹. For the Activity Scale for Kids performance version (ASKp) there were 12 out of 22 children with a score over 95% before the intervention; 6 of those children had a perfect score of 100%. This means that the potential for improvement was very limited. Large numbers of tasks evaluated were too easy for children with GMFCS I or GMFCS II (e.g.: “How often did you stand up from a bed alone?” and “How often did you sit down on a chair alone?”).

Additionally, other parts of the questionnaires were not focused on the lower extremities that were the target of the interventions. Such questions included “Did you brush your teeth without help?” and “Did you put on your shoes alone?”. The Pediatric Outcome Data Collection Instrument (PODCI) included whole subsections on upper extremities and pain. Both questionnaires included sections on activities that were not targeted by the intervention. Even if none of the groups reached a significant level of improvement, the ASKp questionnaire showed a strong trend for improvement within the PRT group ($p=0.051$).

However, a deeper examination using the PODCI subsection scores reveals some improvement of participation measurements in the HICT group despite the ceiling effect. Children scored higher in the basic mobility and transfer, and the happiness scales. The basic mobility scale was one of the functional aspects directly targeted by the intervention. This indicates that parents noted better performance of activities of daily living at home. The happiness scale included some very general questions that are barely affected by lack of specificity or a ceiling effect, for example “How well were you able to keep up with friends?”. This question can improve for very high-functioning children but also severely functionally affected children regardless of the intervention used. There are no subcategories for the ASKp-questionnaire, which means that such an evaluation is only possible for the parent questionnaire.

4.4. Comparison of ICF improvement between interventions

This program was designed with the ICF-model in mind and was the first to show improvement for all main components of this model in the HICT group. Why was the HICT more successful within the ICF-model compared to PRT? Previous research showed that the rate of force development is considerably affected in children with CP⁶. Most activities, such as walking, require rapid development of force over strength^{1,6}. Temporal characteristics of force might be a more optimal target for intervention to impact activities of daily living¹. The improvement of anaerobic power and rapid force development might have been the reason why this study was able to find changes in function and activity level of the ICF and some improvements at the level of participation for the HICT-group¹. This is in contrast to other high-quality papers investigating the effect of PRT¹, which investigated all levels of the ICF but did not show functional improvement^{1,3,10}. Previous research on similar high-velocity training in children with CP was also able to show improvements on one or two ICF components, but has not yet investigated all ICF levels^{1,2,5}.

4.5. Control follow-up phase

As expected, we observed some deterioration during the follow-up phase in both groups¹. The total isometric strength and the mean muscle power in the HICT group showed a significant decline¹. The PRT group also deteriorated in some of the outcome measures (e.g. timed stairs test: -9.9%)¹. These results suggest that while strengthening can improve function in children with CP, improvements do not persist long-term¹. It is essential that children with CP train frequently and consistently to maintain their results¹. Home-based training programs could be a solution that extends institutional physiotherapy and enables consistent long-term intervention¹. A determination of the frequency and intensity of training necessary to retain performance was not the aim of this study and should be analyzed in future studies¹.

4.6. Training time

If a new intervention is planned, time investment is an important aspect for compliance. The average training session in the HICT group lasted for 28 minutes, compared to 40 minutes for the PRT group. A shorter training time is a major incentive for children with CP; most children who follow recommended treatment receive a large amount of interventions throughout their youth, which challenges their compliance and motivation to exercise. For a typical exercise program, children need to travel to a hospital, therapist office, treatment

center, or fitness studio at a specific and fixed time before dressing for the appointment and performing the exercises and returning home. Home-based training, on the other hand, can be performed at any time in the comfort of their own home, without any additional time investment.

Motivation is also often affected by unattainable goals. For many children with CP maintaining their current level of fitness is considered a success because of the natural progression of the disease. However, many children and parents expect increased results, maintaining function is not enough for them to invest a large amount of time or energy. As a result of these major challenges, exercise duration is one of the most important factors that determines whether children exercise, the level of compliance during the exercise, their motivation, their long-term commitment to exercise and as a consequence also the entire outcome of the intervention. The considerably shorter average training session of the exercise program (43%) would be a major advantage of HICT.

4.7. Load

An approximation of the differences in load was provided in lieu of a direct comparison of the load, which was limited by the differences in load application for the two interventions. While the HICT group trained for considerably shorter time periods with less load per exercise, they completed a higher number of repetitions and ended up with a higher overall load (21%). This increased total load of the whole exercise program despite the shorter training time, could be an explanation for the larger strength improvements.

4.8. Correlation

The discussion focuses solely on highly significant correlations ($p < 0.01$), because other, while still significant, correlations only showed weak trends in the corresponding histograms. The identification of these highly significant correlations can be useful for the design of future well powered studies.

There was a relationship between increases of hip abductor strength and the MPST. This shows that strengthening muscles responsible for stance phase stabilization should have the highest impact on functional gains. Future studies might want to put a particular emphasis on those muscle groups in the design of their exercise programs.

Another highly significant correlation was that children with improved knee extensor strength also performed better in the six-minute walk test. Further studies are necessary to investigate a possible reason for this correlation.

To improve function, other skills, such as (e.g.: maximum force, rapid-force development, coordination, balance, and mental aspects must be enhanced in addition to strength. These correlations raise important connections that should be targeted in future studies; they are not suitable to infer any direct causal connections.

4.9. Comparison to previous high-velocity research

HICT is a specific form of high-velocity training. While this was the first study on HICT, there have been multiple similar studies that investigated high-velocity training.

There was only one study that also used intervals¹. Lauglo et al. showed that a 24-session HICT improved the aerobic capacity of patients, although they reported that quality of life did not improve^{1,5}. However, the Lauglo study was not controlled and did not analyze outcome measures of all ICF-components¹. The presented study, alternatively, provides a more extensive analysis of HICT for children with CP and compares it to the gold standard of strengthening exercise in cerebral palsy: PRT¹.

The most successful high-velocity program was developed and investigated by Van Vulpen et al.² with similar population, intervention, and outcome measures. They investigated 22 children with CP, GMFCS I and II, 13 bilateral after a 14-week functional power training focused on functional exercises that relied on short bursts of energy. Their main outcome measure was the MPST, which is also one of the main measures in this study. The functional benefits of this study were considerably larger compared to the gains in this study. Mean muscle power as indicated by the MPST improved by 83% and 10-meter shuttle run results by 56%. Additionally, there were also smaller improvements of gross motor function and a 1-minute walk test.

This difference in improvement between the studies is not surprising because despite its similarities there were also considerable differences between the two studies. Functional benefit of strengthening in children with CP is dependent on the specificity of training. The exercises in the Van Vulpen study targeted sprint improvement, where one of the exercises

featured children running while pulling weights that were trapped to them. The movement, intensity, and muscle groups were identical with those tested in the MPST. This study used alternative exercises to sprinting, such as standing up or heel rises. This was necessary to enable a meaningful comparison to a group training at medium intensity (PRT group). However, it is not possible to carry out specific sprinting exercises at medium intensity which is another key difference between the studies. Additionally, this study investigated home-based training, while the study by Van Vulpen investigated children trained at an institution under constant supervision. This allowed for optimal control of the intervention with optimized execution of each exercise, also it required both a considerably larger time investment by parents and children and additional resources from the health care system. Finally, the two studies investigated different lengths of training intervention. The children in this study trained for 8 weeks compared to 14 weeks in the Van Vulpen study, which indicates that it might be possible to find considerable functional and strength improvements after a shorter period of strengthening. The positive results of both studies show the versatility of high-velocity training as a strengthening tool despite the differences between the studies. High-velocity training can be successful in different settings (at an institution and at home), after different durations (8 weeks or 14 weeks), and with a focus on different goals (sprinting or more moderate functional exercises).

4.10. Home-based training

While it is not clear if home-based training is more beneficial than institutional training, the results of this study indicate that home-based strength training is a valuable additional intervention in children with CP, one that can extend institutional training and enable more affordable and frequent strength training¹. The intention is not to completely replace institutional training but to complement and support it with home-based training. For example, home-based training could be an inexpensive and effective intervention that is added when the child is not receiving medical care through institutional interventions. This reduction of periods between interventions could lead to an improved overall result.

The trends in this study are in agreement with the results of other studies that investigated the benefits of home-based training in children with cerebral palsy using other forms than strengthening and older basic studies on strengthening¹¹⁻¹⁴.

Home-based exercise training is still being perfected. Additional developments might make home-based intervention even more relevant and feasible to use. Computer assisted therapy, internet-based physiotherapy, and robotics can increase the quality of therapy and can ensure that the children perform the exercises in a way similar to an institutional setting¹⁵⁻¹⁷. Those tools can also help ensure adequate motivation and intensity within the training.

Despite both trainings being home-based exercise programs, both interventions showed a high training compliance (HICT:88% / PRT:86%)¹, which is comparable to similar institutional studies^{1,3,10}. This shows that children with CP can be motivated to follow exercise programs at home¹.

4.11. Variability in responses

This study found considerable variability in the individual response to training. Some children showed improvement far above average while other children showed no improvement at all. This high variability was consistent over most outcome measures and showed no clear correlation to any basic characteristics.

This is consistent with most other studies on strengthening for children with CP^{9,13,18,19}. While these studies usually find improvement of mean outcome measures, there is also usually a considerable difference in individual improvement. The reason for these differences has yet to be determined. Variability is a problem because even if an intervention shows a benefit for the average participant, it is not possible to assess whether a particular patient in clinical practice will be a strong responder or a non-responder. A study on healthy adults has shown that considerable differences in outcome after exercise intervention were not primarily explained by different lifestyles, environment, age, or other factors, indicating the cause might be genetic²⁰. Congenital anomalies can be found in up to 40% of CP registers in Australia, meaning that the effect of genetics on strengthening in CP is probably even higher compared to healthy adults. This was confirmed by a recent study that investigated the association between variation in dopamine genes and treatment outcomes, which found that children with a higher polygenetic dopamine gene score had better outcomes after exercise²¹. Future strength training might include individually tailored programs based on the genetic profile of the specific patient.

4.12. Interpersonal differences

Children with CP have high degrees of interpersonal variations and the impact of the disease can vary from day to day. There were children in this study that had a “bad day” because they were considerably influenced by the disease or external factors at the pre- and post-intervention values. This study was designed for a future clinical application as an intention to treat analysis. As a result, there were no statistical corrections for any interpersonal differences. However, a closer investigation of the control phase shows that there were indeed considerable changes of outcome measures within the control phase, but those positive and negative changes offset each other and there was no significant difference for any outcome measures. It is very likely that the same effect also occurred within the intervention phase. Despite the lack of statistical correction, it is unlikely that any interpersonal difference impacted the results and conclusions of this study.

4.13. Case study balance

Previous strengthening research suggested that the reason for lack of functional improvement might be that the children improved other skills that were not captured by the outcome measurements used. This section will examine this theory using a case study focusing on one child.

The participant was a high-functioning diplegic 13-year-old girl with GMFCS I who was randomized to the HICT group. The girl and her mother showed a high compliance during examinations, instruction, intervention, and post-intervention. She completed 100% of all training sessions and showed a considerable increase of repetitions for each exercise during the training period. Both mother and child evidenced a high rate of satisfaction with the exercise program and its result. However, the objective outcome measures of this study showed no considerable improvements. Neither strength, nor function, nor patient-reported outcomes improved. Mother and child were asked how they think the child benefited from the program and they stated that they noticed considerable balance improvements. There were multiple exercises that demanded balance (heel rises, lunges, lateral step-ups). While this study did not evaluate balance, we had static balance measurements for this particular patient from a trial measurement during the pre-intervention evaluation. Based on the patient feedback, the same examination was also carried out post-intervention. The child had to stand still on a force plate for 30 seconds first with eyes open, then with eyes closed. The force plate

data was used to calculate velocity and sway of the center of pressures for both conditions. The child showed clinically meaningful improvement of these parameters.

Functional exercises require multiple skills, strength, velocity, coordination, balance, and more. While the optimal performance for an exercise might be restricted by strength in one child, another child might have enough strength for this exercise but is restricted by balance. This case study suggests that the same exercise might train strength in one child but improve balance in other children. A non-response of a child for one aspect of movement does not necessarily mean that the child did not benefit at all. A considerable amount of actual improvement might not have been captured, as this case study indicates. Despite the large amount of outcome measures used in this study there was potential improvement that was not measured.

4.14. Dropouts

Most of the children (4 out of 5) who dropped out of the study were part of the HICT group, however, this rate was similar to previous high-intensity training research^{1,5}. High-intensity training requires maximum effort, which requires a high level of motivation and cooperation from child and parent¹. All dropouts of this study were due to the lack of motivation¹. While high-intensity training seems to be an effective intervention to improve strength and function in children with CP, it is only recommended when there is adequate compliance in both parent and child¹.

Five children recruited for this study had some problems following the concepts, purpose, and instructions of the training program. Three of those five children were among the five dropouts within the intervention phase. High intensity training is very challenging, and it is difficult to maintain intensity. Therefore maintaining compliance is extremely difficult for children who have trouble maintaining attention and who might not completely comprehend the importance and relevance of exercising. HICT might be preferable to PRT but only for children who are able to completely commit to the training regimen. A more moderate training might be more appropriate for children who are not motivated to exercise.

4.15. Study limitations

This was the first study investigating HICT in children with CP¹. As a result, it was not possible to provide a sample size calculation¹. While there were several significant results and

clinically meaningful improvements, the post-hoc power analysis shows that only the strength improvements and the PODCI “happiness” improvement were powered enough. Although, the results on functional improvement are encouraging for the future for HICT in children with CP, it is not possible to make any definite statements based on the results of this study. However, the data provided can be used for the design and optimization of future well-powered studies on the issue.

This study did not control for multiple observations and therefore has an increased risk of alpha errors. This is a valid approach for a pilot study that is designed to provide the information to generate hypotheses for new studies and is not primarily focused on final clinical statements, which makes an alpha error acceptable. However, the actual impact of this was minimal. The main findings of the study would have persisted even after correction for multiple observations. There would have been significant strength improvement only in the high-intensity group and functional improvement specific to the intervention in both groups. Only the timed up-and-go test would not have shown significant improvements in the PRT group as well as two sub-categories that were not among the primary outcome-measures (PODCI-Transfer and specific HHD-muscle groups).

The exercise programs were intentionally designed as a home-based intervention with the goal of a clinical application¹. However, this study design might have some disadvantages, especially because home-based programs lack a tight control of day-to-day execution of the training program¹. However, the control mechanisms that were employed in this study showed a high level of acceptance and understanding of the exercise programs¹.

There is reason to believe that the improvement of several outcome measurements was underestimated because of a small number of missing values. Strength results did not include two children because they could not selectively activate an evaluated muscle group, but both were able to activate the muscle groups after the intervention. The gains of their other muscle groups would have been above the average of the remaining participants. Therefore our determination was that the missing values did not adversely affect the results of the study.

4.16. Conclusion

This study investigated two home-based strengthening programs in children with CP: progressive resistance training (PRT) and high intensity circuit training (HICT). While

children in both groups showed functional improvement specific to the intervention only the HICT group showed improvement in strength and participation improvement¹. A closer investigation of the sprint test showed that the children primarily improved in functional consistency rather than maximum performance. The average training time in the HICT group was considerably shorter than that of the PRT group. Although participating in HICT required higher motivation, compliance to the training in this study was excellent and comparable to the PRT-group.

The study also indicated that home-based strengthening is a valuable option for strength-training intervention, that can supplement institutional interventions. It is both a cost-effective and easily accessible method for highly functional and motivated children with CP¹.

5. Supplemental materials

5.1. Skeletal muscle physiology

The vast majority of muscle tissue is formed by skeletal muscle¹¹⁰. It provides the mechanical power necessary for locomotion and other activities of daily living through muscle contraction¹¹⁰. Muscle contraction is the result of an interaction between two proteins actin and myosin¹¹¹. Figure 4 presents the structure of the skeletal muscle.

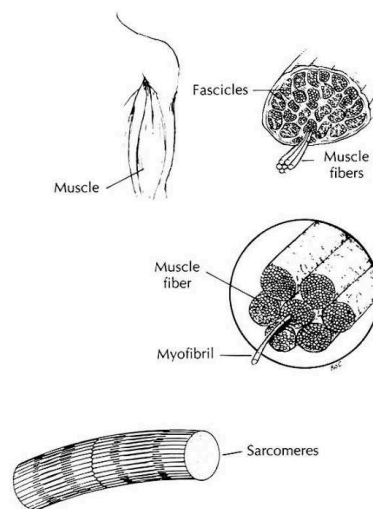


Figure 13: structure of the skeletal muscle, available at open access reference¹¹²

Actin and myosin are contained within the main contractile unit of the human body, sarcomeres¹¹². Multiple sarcomeres are found within myofibrils. Myofibrils are included within muscle fibers. Multiple fibers form a muscle fascicle and all muscle fascicles together represent the skeletal muscle

Multiple muscle fascicles are innervated by a single alpha-motor neuron. Motor neuron and muscle fascicle together form the motor unit. The motor neuron sends an activation potential to the muscle fascicle which is transferred at the motoric end plate. The force of a muscle contraction depends on the number of motor units that are activated by the central nervous system¹¹³.

Speed and endurance of a contraction depend on the type of muscle fibers activated¹¹⁴. Different types of muscle fibers vary in contraction speed and energy metabolism. Based on their predominant myosin heavy chain isoform content they can be classified as type I slow

twitch fibers or type II fast twitch fibers¹¹⁴. Type II fibers can be further classified based on the metabolic properties (oxidative or glycolytic).

Muscle strength is also considerably influenced by muscle architecture. A thicker muscle with an increased physical cross-sectional area and muscle fiber diameter, is able to produce a higher force¹¹³. Contraction velocity is influenced by the length of a muscle, fascicle length and fiber length.

The length of a muscle also determines the distance over which a fiber can shorten. This is important because the available muscle strength varies at different lengths. It depends on the current number of actin-myosin interactions which is different based on the current sarcomere length. This principle is presented in Figure 5. It presents the overlap of actin and myosin filaments at different lengths. At point 1 the muscle is overly contracted, with actin filaments sliding over each other which restricts force production. Point 2 shows sarcomeres at their optimal length (2.1 to 2.2 μm). This is the position with the largest actin, myosin overlap thus the muscle can produce the largest amount of force. At point 3 and 4 actin filaments start to pull away from the myosin heads which decreases the possible muscle force.

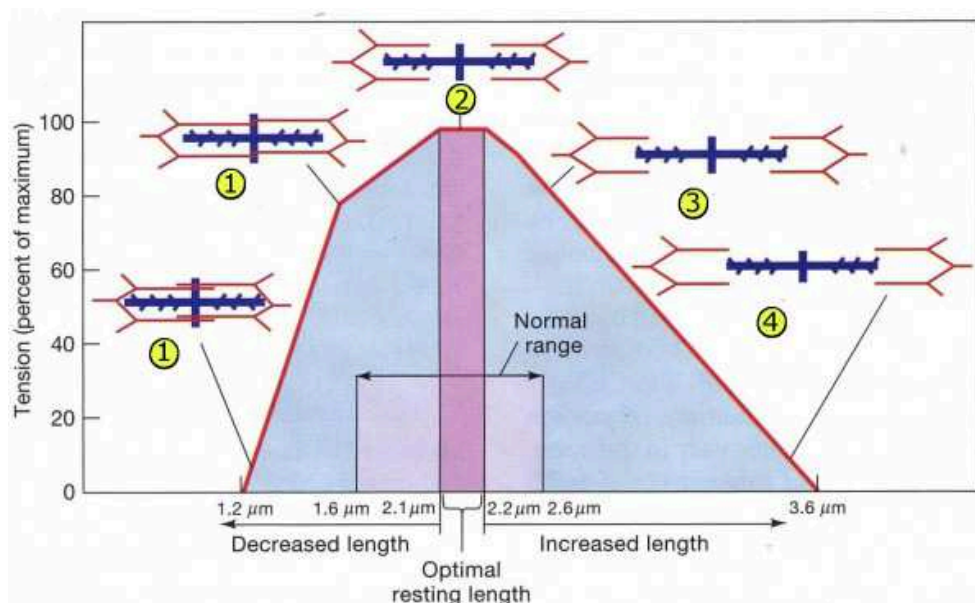


Figure 14: length tension curve of a skeletal muscle with actin and myosin overlap at different length (freely available online)¹¹⁵

The length of a muscle also has direct influence on the lever arm. Each muscle applies a specific force at a certain lever arm which moves a weight at a distance from the joint center. If the force is applied at a larger distance from the joint center than the weight there is a mechanical advantage¹¹⁶.

5.2. Strength measurement

Muscle strength is affected in children with cerebral palsy¹¹⁷. Assessing muscle strength in children with CP is essential to monitor clinical progress, to identify muscle groups that should be targeted by strength training, to determine the load for that training and to monitor the progress and necessary adjustments to training. The most reliable way to measure muscle strength in a clinical setting is hand held dynamometry, which has been used for over 15 years to assess strength in cerebral palsy¹¹⁸.

The hand-held dynamometer is a device equipped with an internal system that can measure the force applied in Newton. It is held against the leg of the patient and when the patient pushes against the device the applied force is displayed. There are several challenges in measuring strength in children with cerebral palsy, lack of understanding, selective control, problems applying force directly and muscle synergies^{32,119}

There is mixed research on the reliability of HHD-measurements in cerebral palsy. One study showed acceptable within session reliability but low between-session reliability for hip extensors, plantar flexors and dorsal flexors in children with cerebral palsy¹¹⁸. Another study with improved testing positions and statistical analysis found acceptable intertester reliability and moderate to high intratester reliability but did not test between session reliability¹⁰⁰.

Table 17: Standardized positioning of the HHD

Muscle group	Positioning of the patient	Positioning of the HHD
Hip extensors	Supine, hip and knee flexed at 90 degrees	3 cm proximal of popliteal crease
Hip flexors	Supine, hip and knee flexed at 90 degrees	3cm proximal of superior border of patella
Hip abductors	Supine, hip flexed slightly (~5 degree), Knee 0 degree	5cm proximal of lateral epicondyle
Hip adductors	Supine, hip flexed slightly (~5 degree), Knee 0 degree	5cm proximal of medial epicondyle
Knee extensors	Sitting, hip and knee at 90 degrees	5cm proximal of lateral malleoli
Knee flexors	Sitting, hip and knee at 90 degrees	5cm proximal of lateral malleoli
Dorsal extensors	Supine, hip and knee at 0 degree	Top of metatarsal heads
Plantar flexors	Supine, hip and knee at 0 degree with the bed against the wall and the hand-held dynamometer between wall and plantar surface with the examiner stabilizing the hand-held dynamometer.	Plantar at the position of metatarsal heads

5.3. Muscle Power Sprint test

A lot of daily childhood activities require short-term high intensity activity instead of long-term activity⁷⁴. However most of the current research on children with cerebral palsy is focused on aerobic capacity and muscle strength, while less attention is given to high intensity activities that last only a few seconds. Anaerobic capacity might be a better measure of functional ability than aerobic tests¹. Activities such as running are more similar to the typical physical behavior seen in high functioning children with cerebral palsy classified GMFCS level I and II¹²⁰.

The Muscle Power Sprint test was developed as a tool to measure this anaerobic capacity in children with cerebral palsy. This test is reliable, non-threatening, inexpensive and easy to administer in a non-research setting¹²⁰. There is an extensive set of reference values for children with cerebral palsy¹²¹.

The Muscle Power Sprint is reliable and its construct validity is established in children with cerebral palsy classified as GMFCS I or II and has been used successfully in other strengthening studies in children with cerebral palsy¹²².

5.4. 6-minute walk test

The optimal parameter to measure cardiopulmonary performance would be to measure peak oxygen uptake in a laboratory setting¹²³. However, this test takes considerable time and children have sometimes difficulty accepting the mask when exercising. For that reason, this study evaluated the six-minute walk test as a surrogate measurement for aerobic capacity.

The six-minute walk test is a low tech, easy to use clinical test to measure aerobic fitness. It captures the distance walked within 6 minutes at normal walking speed. While the 6-minute walk test does not directly determine peak oxygen uptake, the cause of exertion or evaluates exercise limitation, it correlates closely with VO₂ peak measurements¹²³. The information provided by the 6-minute walk test, may be an even better index of functional ability in activities of daily living compared to peak oxygen uptake¹²⁴.

The six minute walk test is reliable in children with cerebral palsy¹²⁵. It has already been used in studies on strengthening in children with cerebral palsy⁷².

5.5. Timed up-and-go test / Timed stairs test

There are a multitude of skills which are affected in children with CP that are required for activities of daily living (e.g. strength, balance, coordination and more). The timed up-and-go test is a basic mobility test that was originally developed for elderly people and is suited as a test for a multitude of skills¹²⁶. This test requires balance control, movement through planning, initiating, executing and completing an integrated movement sequence and movement control. All of these skills are diminished in children with cerebral palsy¹²⁷.

The timed stairs test is another test in this study that also assesses a multitude of these skills. The difference between the timed up-and-go test and the timed up and down stairs test is that the timed up and down stairs test measures a higher level of function. It requires an increased amount of strength, balance, coordination and movement control compared to the timed up-and-go test.

Both outcome measures are valid and reliable and have been previously used in strengthening research in children with cerebral palsy^{63,128-130}.

5.6. Gait analysis

Children with cerebral palsy suffer from a wide degree of different gait deviations. Clinical gait analysis allows clinicians to better understand these deviations and base their decisions on additional and more precise information¹³¹. It provides a better understanding of the effect of each treatment and intervention.

Gait analysis allows a more accurate assessment of gait deviations compared to visual assessment and is widely accepted as a research tool. Gait analysis can change treatment decision making and reinforce existing treatment plans. Gait and functional outcomes are improved if gait analysis was performed before an intervention.

Gait analysis provides kinematic and kinetic data. Kinematic data illustrates the movement of the child described in gait analysis by the angular deviations of different joints/segments: pelvis, hip, knee and ankle¹³¹. The raw data for this analysis is captured by infrared cameras that determine the position of passive reflective markers. These markers are precisely attached to anatomical landmarks that define each body segment. The most common model to define these segments which is also used in this study is called “Plug-InGait”¹³¹. Kinetic data describes the forces applied by the patient during gait which corresponds to the ground-reaction forces, joint moments and powers of each joint. Data captured by force plates embedded in the ground is used for this analysis¹³¹.

As a result, gait analysis has been extensively used in research to understand the efficacy, effect and mechanism of all sorts of interventions for children with cerebral palsy. It has also already been thoroughly employed in strengthening research although with limited results^{32,63}.

5.7. Activity Scale for kids performance version (ASKp)

Cerebral palsy affects the frequency of participation in activities and social situations such as community activities, sports and other events of daily living¹³². It is essential to document the impact of any intervention on the environment of children and their participation in daily life¹³³. The ASKp is a self-reported questionnaire that captures the ICF-participation level from the view of the child. The ASK was designed as a self-report outcome measure of activity and physical function for children aged 5 to 15 years.

The ASK is an assessment of a child's physical disability using domains such as personal care, dressing, locomotion, playing, standing skills and transfer¹³². It is completed by the children themselves without any parental intervention or information. If the child is unable to answer some questions alone, the parents are allowed to assist and their level of assistance is documented.¹³⁴.

There are two versions of the ASK, the ASK-capability (ASKc) that measures what the child is able to do and the ASK-performance that measures what the child actually does. This study only uses the ASKp. The ASKp assesses the environment of each child and how it operates in that environment¹³³.

It is valid and reliable in children and it has already been used in studies on children with cerebral palsy^{135,136}.

5.8. Pediatric Outcome Data Collection Instrument (PODCI)

The PODCI is another questionnaire that measures participation which is completed by the parents. It was developed as an outcome measure to assess changes after pediatric orthopedic intervention for a broad range of different diagnoses, one of those is children with cerebral palsy whose function is minimal to moderately impaired with a Gross Motor Classification System level between I and III¹³⁷.

There are seven sub-constructs within the PODCI, upper extremity function, transfer, mobility, physical function and sports, comfort, happiness, satisfaction and expectations. The single elements range from very simple tasks like standing up from a chair to high functioning tasks like competitive sports¹³⁸.

The reliability, internal consistency and discriminant validity of all those dimension has been established¹³⁷ and it has been used in multiple studies on strengthening in cerebral palsy^{74,139}.

5.9. Exercise descriptions

5.9.1. Adapted sit to stand

Properties: 3 sets, PRT: 10-12 repetitions with the load determined by 10 repetition max test, HIIT: 30 seconds with as many repetitions as possible at maximum speed without load.

Type of Exercise: bilateral exercise targeting hip flexors, hip extensors, hip abductors, knee flexors, knee extensors

Starting position:



Figure 15: Starting position adapted sit to stand

The participant is standing in front of the chair, legs hip width apart and parallel with extended hips and knees.

Instruction: Sit down with controlled knee axis and controlled upper body without using hands or upper body for support. When the buttocks is slightly touching the seat, stand up again.

End position



Figure 16: End position adapted sit to stand

Almost sitting on the chair, slightly touching it but with no body weight on it.

Correct Trial: A correct trial required a correct axis in all joints, a stable upper body, hip wide stance throughout and a starting position not too near or far from the chair. It is important that the child goes through the whole movement which means returning all the way back to the starting position.

Adaptations: The most frequent problem was that some children were not able to lower their body all the way to the chair without sitting down. They were instructed to move as far as possible without sitting down and then return to the starting position.

5.9.2. Heel rises

Properties: 3 sets, PRT: 10-12 repetitions with the load determined by 10 repetition max test, HIIT: 30 seconds with as many repetitions as possible at maximum speed without load.

Type of Exercise: Bilateral exercise targeting plantar flexors

Starting position:



Figure 17: starting position heel rises

Standing on the floor in hip wide stance with stable upper body and hips and knees extended.

Instruction: Lift heels as high as possible and lower them back to the ground as slowly as possible.

End position



Figure 18: End position heel rises (This figure was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)

Standing on the toes with the heel lifted as high as possible, with extended hips and knees and the heels plantar flexed with a stable upper body.

Correct Trial: Heels lifted as high as possible, the foot is lowered slowly, controlled back to the floor and not dropped without muscle tensions. Knee axis, hip wide stance and upper body, stay controlled throughout.

Adaptations: The main problem for this exercise were balance issues when the children stood on their toes. The goal of this exercise was muscle strengthening and not balance training. As a consequence, children were allowed to hold on to someone or something for balance and support and ensure that balance issues didn't limit the strength that could be used within this exercise.

5.9.3. Lunges

Properties: 3 sets for each side, PRT: 10-12 repetitions with the load determined by 10 repetition max test, HIIT: 30 seconds with as many repetitions as possible at maximum speed without load.

Type of Exercise: Unilateral exercise targeting hip extensors, flexors, abductors and knee flexors and extensors.

Starting position:



Figure 19: Starting position Lunges

Standing with extended hips and knees

Instruction: Take a big step forward and lower the contra lateral knee as close to the floor as possible without touching it. Then move back to the starting position.

End position:



Figure 20: End position Lunges (this figure was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)

Knee and hip flexed at 90° on one side, knees flexed, and hips extended on the other side.

Correct Trial: A correct trial is executed when the knee axis in both legs and the upper body remains stable. The step needs to be far enough so that 90° Knee flexion is reached when the contra lateral leg is close to the ground.

Adaptations: Similar to heel rises, several children were allowed to hold on to support balance. Some children were not able to take a step that was large enough without moving the contra lateral foot or were not able to go all the way down to the floor. They were allowed to make smaller steps. Additionally, they were told to establish a visual line of how far the step is to ensure that they maintain step length and increase step length once they progressed.

5.9.4. Bridging

Properties: 3 sets, PRT: 10-12 repetitions with the load determined by 10 repetition max test, HIIT: 30 seconds with as many repetitions as possible at maximum speed without load.

Type of Exercise: trunk exercise on the floor targeting hip extensors and trunk muscles.

Starting position:



Figure 21: Starting position bridging

Supine on the floor with knees flexed 90° and the torso lifted off the floor.

Instruction: Lift one foot slightly off the ground and put it right back down again. For the next repetition do the same thing with the other foot. The torso stays lifted throughout the whole exercise, without dropping down.

End position:



Figure 22: End position bridging

Same as the starting position with one foot slightly lifted off the floor

Correct Trial: The participant can maintain a straight line between head and knee. The hip never drops, and hip wide stance is maintained.

Adaptations: Several children did not have enough strength for this exercise. They were told to maintain the starting position as long as possible and do as many repetitions as possible but progress to the correct execution as fast as possible. One patient was not able to perform this exercise because of a recent open cranium wound. He was instructed a similar exercise targeting the same muscles to the same degree.

5.9.5. Lateral step ups

Properties: 3 sets for each side, PRT: 10-12 repetitions with the load determined by 10 repetition max test, HIIT: 30 seconds with as many repetitions as possible at maximum speed without load.

Type of Exercise: Unilateral exercise targeting hip abductors, hip extensors and knee extensors

Starting position:



Figure 23: Starting position lateral step ups

Both feet on the stepper close to the edge with extended hips and knees.

Instruction: Move the lateral foot towards the ground, heel first. When it first touches the floor slightly without putting weight on the foot move the foot back to the starting position.

End position:



Figure 24: End position Lounges (this figure was reproduced from the article by Schranz et al. ¹ and is covered by the licensing agreement of the article)

The medial leg is on the stepper, knees and hips slightly flexed. The lateral leg is slightly touching the floor. The upper body remains stable.

Correct Trial: Stable upper body, correct knee axis, no hip flexion or extension on the lateral side, the lateral leg moves towards the floor next to the body. This exercise should not be executed with too much plantar flexion which would allow the child to reach the floor quicker.

Adaptations: Some children needed slight balance support similar to previous exercises “heel rises” and “lunges”. There were children who could not reach the floor on both sides at the start of training. They were instructed to move as low as possible.

5.10. Additional correlation tables

Table 18: Correlation between main outcome measures and baseline characteristics of the whole group:
Pearson correlation coefficient (p-value) for differences between T1 and T2

Correlation	Basic characteristics					
	GMFCS	Gewicht	Größe	HeDi	Gender	Age
Total Strength (N/kg)	0,24 (0,30)	0,23 (0,31)	0,18 (0,45)	-0,16 (0,49)	-0,31 (0,17)	0,24 (0,29)
Mean Muscle Power	-0,16 (0,48)	0,35 (0,11)	0,3 (0,18)	0,37 (0,09)	0,21 (0,35)	0,27 (0,23)
Max Muscle Power	0,24 (0,29)	-0,40 (0,07)	-0,45* (0,04)	0,47 (0,03)	-0,11 (0,64)	-0,37 (0,10)
Min Muscle Power	-0,23 (0,30)	0,42* (0,05)	0,44* (0,04)	0,18 (0,43)	0,17 (0,44)	0,40 (0,07)
Timed Up-and-go Test (seconds)	-0,46* (0,03)	0,01 (0,96)	-0,04 (0,86)	0,16 (0,47)	0,21 (0,36)	-0,24 (0,29)
Timed Stairs Test (seconds)	-0,07 (0,75)	0,30 (0,18)	0,37 (0,09)	0,0 (0,99)	-0,17 (0,46)	0,27 (0,23)
6 minute walk test (meters)	0,10 (0,66)	-0,12 (0,58)	-0,17 (0,46)	-0,22 (0,33)	-0,15 (0,50)	-0,01 (0,95)
Energy Expenditure Index (Score)	0,26 (0,25)	0,23 (0,30)	0,30 (0,17)	-0,02 (0,93)	-0,19 (0,39)	0,26 (0,24)
GPS (°)	0,09 (0,70)	-0,06 (0,79)	-0,07 (0,75)	0,28 (0,21)	0,23 (0,30)	0,06 (0,80)
ASKp	0,0 (1,0)	0,10 (0,66)	0,07 (0,75)	-0,24 (0,29)	0,05 (0,82)	0,07 (0,77)
PODCI	-0,07 (0,76)	-0,47* (0,03)	0,33 (0,14)	0,17 (0,47)	0,08 (0,73)	0,36 (0,11)

PRT, Progressive Resistance Training; HICT, High intensity Circuit Training ; PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; * $p < 0,05$; **

$p < 0,01$

Table 19 Correlation between parameters of activity/participation: Pearson correlation coefficient (p-value) for differences between T1 and T2

Correlation	MeanP	Activity/participation outcome measures						
		TUG	TST	6m	EI	GPS	ASKp	PODC
Mean Muscle Power	X	0,25	0,18	0,13	0,27	0,17	-0,10	0,50*
		(0,26)	(0,43)	(0,56)	(0,22)	(0,44)	(0,66)	(0,02)
Max Muscle Power	X	-0,0	-0,14	-0,09	-0,05	0,14	0,01	-0,23
		1,0	(0,53)	(0,70)	(0,83)	(0,55)	(0,96)	(0,32)
Min Muscle Power	X	0,14	0,33	0,09	0,26	0,07	-0,16	0,44*
		(0,53)	(0,14)	(0,68)	(0,25)	(0,75)	(0,47)	(0,05)
Timed Up-and-go Test (seconds)	0,25	X	-0,01	0,12	-0,14	-0,03	-0,01	-0,05
		(0,26)	(0,97)	(0,61)	(0,53)	(0,91)	(0,96)	(0,82)
Timed Stairs Test (seconds)	0,18	-0,01	X	-0,22	0,14	0,07	-0,43*	-0,41
		(0,43)	(0,97)	(0,34)	(0,53)	(0,76)	(0,04)	(0,06)
6 minute walk test (meters)	0,13	0,12	-0,22	X	0,08	0,18	0,14	0,18
		(0,56)	(0,61)	(0,34)	(0,73)	(0,43)	(0,54)	(0,45)
Energy Expenditure Index (Score)	0,27	-0,14	0,14	0,08	X	0,35	0,32	0,21
		(0,22)	(0,53)	(0,53)	(0,73)	(0,11)	(0,15)	(0,35)
GPS (°)	0,17	-0,03	0,07	0,18	0,35	X	0,24	-0,19
		(0,44)	(0,91)	(0,76)	(0,43)	(0,11)	(0,29)	(0,40)
ASKp	-0,10	-0,01	-0,43*	0,14	0,32	0,24	X	0,24
		(0,66)	(0,96)	(0,04)	(0,54)	(0,15)	(0,29)	(0,30)
PODCI	0,50*	-0,05	-0,41	0,18	0,21	-0,19	0,24	X
		(0,02)	(0,82)	(0,06)	(0,45)	(0,35)	(0,40)	(0,30)

PRT, Progressive Resistance Training; HICT, High intensity Circuit Training ; PWR, Power; GPS, Gait Profile Score; ASKp, Activity Scale for Kids performance Version; PODCI, Pediatric Outcome Data Collection Instrument; Diff, Difference between T1 and T2; * $p < 0,05$; **

$p < 0,01$

6. References

1. Schranz C, Kruse A, Belohlavek T, et al. Does Home-Based Progressive Resistance or High-Intensity Circuit Training Improve Strength, Function, Activity or Participation in Children with Cerebral Palsy. *Arch Phys Med Rehabil*. 2018. doi:<http://dx.doi.org/10.1016>
2. Kavčič A, Vodušek DB. A historical perspective on cerebral palsy as a concept and a diagnosis. *Eur J Neurol*. 2005;12(8):582-587. doi:10.1111/j.1468-1331.2005.01013.x
3. Christensen D, Braun N, Doernberg NS, et al. Prevalence of cerebral palsy, co-occurring autism spectrum disorders and motor functioning. 2015;56(1):59-65. doi:10.1111/dmcn.12268.Prevalence
4. Rosenbaum P. Cerebral palsy: what parents and doctors want to know. *Bmj*. 2003;326(7396):970-974. doi:10.1136/bmj.326.7396.970
5. Smithers-Sheedy H, Badawi N, Blair E, et al. What constitutes cerebral palsy in the twenty-first century? *Dev Med Child Neurol*. 2014;56(4):323-328. doi:10.1111/dmcn.12262
6. Rethlefsen SA, Ryan DD, Kay RM. Classification systems in cerebral palsy. *Orthop Clin North Am*. 2010;41(4):457-467. doi:10.1016/j.ocl.2010.06.005
7. Pidgeon TS, Ramirez JM, Schiller JR. Orthopaedic Management of Spasticity. *R I Med J (2013)*. 2015;98(12):26-31. <http://www.ncbi.nlm.nih.gov/pubmed/26623452>. Accessed June 28, 2018.
8. Molnar GE. Rehabilitation in cerebral palsy. *West J Med*. 1991;154(5):569-572. <http://www.ncbi.nlm.nih.gov/pubmed/1866952><http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1002833>.
9. Miller F. *Cerebral Palsy*. Springer; 2005.
10. Eggink H, Kremer D, Brouwer OF, et al. Spasticity, dyskinesia and ataxia in cerebral palsy: Are we sure we can differentiate them? *Eur J Paediatr Neurol*. 2017;21(5):703-706. doi:10.1016/j.ejpn.2017.04.1333
11. Fogel BL. Childhood cerebellar ataxia. *J Child Neurol*. 2012;27(9):1138-1145. doi:10.1177/0883073812448231
12. Wood E, Rosenbaum P. The gross motor function classification system for cerebral palsy: A

- study of reliability and stability over time. *Dev Med Child Neurol*. 2000;42(5):292-296.
doi:10.1017/S0012162200000529
13. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol*. 1997;39(4):214-223. <http://www.ncbi.nlm.nih.gov/pubmed/9183258>. Accessed October 28, 2014.
 14. Rodda JM, Graham HK, Nattrass GR, Galea MP, Baker R, Wolfe R. Correction of severe crouch gait in patients with spastic diplegia with use of multilevel orthopaedic surgery. *J Bone Joint Surg Am*. 2006;88(12):2653-2664.
 15. Sharan D. Orthopedic surgery in cerebral palsy: Instructional course lecture. *Indian J Orthop*. 2017;51(3):240-255. doi:10.4103/ortho.IJOrtho_197_16
 16. Day S, Wu Y, Strauss D, Shavelle R, Reynolds R. Change in ambulatory ability of adolescents and young adults with cerebral palsy. *Dev Med Child Neurol*. 2007;49(9):647-653 7p. doi:DMCN647 [pii]\r10.1111/j.1469-8749.2007.00647.x
 17. Bell KJ, Ounpuu S, DeLuca PA, Romness MJ. Natural progression of gait in children with cerebral palsy. *J Pediatr Orthop*. 22(5):677-682.
 18. Hanna SE, Rosenbaum PL, Bartlett DJ, et al. Stability and decline in gross motor function among children and youth with cerebral palsy aged 2 to 21 years. *Dev Med Child Neurol*. 2009;51(4):295-302. doi:10.1111/j.1469-8749.2008.03196.x
 19. Shortland A. Muscle deficits in cerebral palsy and early loss of mobility: can we learn something from our elders? *Dev Med Child Neurol*. 2009;51 Suppl 4:59-63. doi:10.1111/j.1469-8749.2009.03434.x
 20. Graham HK, Rosenbaum P, Paneth N, et al. Cerebral palsy. *Nat Rev Dis Prim*. 2016;2:15082. doi:10.1038/nrdp.2015.82
 21. Damiano DL, Dodd K, Taylor NF. Should we be testing and training muscle strength in cerebral palsy? *Dev Med Child Neurol*. 2002;44(1):68-72. <http://www.ncbi.nlm.nih.gov/pubmed/11811654>. Accessed November 6, 2014.
 22. Tedroff K, Löwing K, Jacobson DNO, Åström E. Does loss of spasticity matter? A 10-year follow-

- up after selective dorsal rhizotomy in cerebral palsy. *Dev Med Child Neurol*. 2011;53(8):724-729. doi:10.1111/j.1469-8749.2011.03969.x
23. Scholtes VAB, Becher JG, Beelen A, Lankhorst GJ. Clinical assessment of spasticity in children with cerebral palsy: A critical review of available instruments. *Dev Med Child Neurol*. 2006;48(1):64-73. doi:10.1017/S0012162206000132
 24. Jefferson RJ. The treatment of gait problems in cerebral palsy. *Arch Dis Child*. 2005.
 25. Shamsoddini A, Amirsalari S, Hollisaz MT, Rahimniya A, Khatibi-Aghda A. Management of spasticity in children with cerebral palsy. *Iran J Pediatr*. 2014;24(4):345-351. doi:10.3944/AOTT.2009.081
 26. Mandigo CE, Anderson RCE. Management of childhood spasticity: a neurosurgical perspective. *Pediatr Ann*. 2006;35(5):354-362. <http://www.ncbi.nlm.nih.gov/pubmed/16722294>. Accessed July 21, 2018.
 27. Trompetto C, Marinelli L, Mori L, et al. Pathophysiology of spasticity: Implications for neurorehabilitation. *Biomed Res Int*. 2014;2014. doi:10.1155/2014/354906
 28. Zonta MB, Bruck I, Puppi M, Muzzolon S, De Carvalho Neto A, Dos Santos LHC. Effects of early spasticity treatment on children with hemiplegic cerebral palsy: A preliminary study. *Arq Neuropsiquiatr*. 2013;71(7):453-461. doi:10.1590/0004-282X20130061
 29. Mehrholz J, Wagner K, Meißner D, et al. Reliability of the Modified Tardieu Scale and the Modified Ashworth Scale in adult patients with severe brain injury: a comparison study. *Clin Rehabil*. 2005;19(7):751-759. doi:10.1191/0269215505cr889oa
 30. Mathewson M a., Lieber RL. Pathophysiology of Muscle Contractures in Cerebral Palsy. *Phys Med Rehabil Clin N Am*. 2015;26(1):57-67. doi:10.1016/j.pmr.2014.09.005
 31. Barrett RS, Lichtwark GA. Gross muscle morphology and structure in spastic cerebral palsy: a systematic review. *Dev Med Child Neurol*. 2010;52(9):794-804. doi:10.1111/j.1469-8749.2010.03686.x
 32. Wiley ME, Damiano DL. Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol*. 1998;40(2):100-107. <http://www.ncbi.nlm.nih.gov/pubmed/9489498>. Accessed November 6, 2014.

33. Verschuren O, Smorenburg ARP, Luiking Y, Bell K, Barber L, Peterson MD. Determinants of muscle preservation in individuals with cerebral palsy across the lifespan: a narrative review of the literature. *J Cachexia Sarcopenia Muscle*. 2018. doi:10.1002/jcsm.12287
34. Booth C, Cortina-Borja M, Theologis T. Collagen accumulates within the muscles of children with cerebral palsy and correlates with the severity of spasticity. 2001:314-320. <http://discovery.ucl.ac.uk/47213/>.
35. Tedroff K. Children With Spastic Cerebral Palsy : Aspects of Muscle Activity and Botulinum Toxin a. 2009.
36. Rose J, McGill KC. Neuromuscular activation and motor-unit firing characteristics in cerebral palsy. *Dev Med Child Neurol*. 2005;47(5):329-336. <http://www.ncbi.nlm.nih.gov/pubmed/15892375>. Accessed July 21, 2018.
37. Leblanc A, Taylor BA, Thompson PD, et al. Relationships between physical activity and muscular strength among healthy adults across the lifespan. *Springerplus*. 2015;4(1). doi:10.1186/s40064-015-1357-0
38. Carroll KL, Leiser J, Paisley TS. Cerebral Palsy: Physical Activity and Sport. *Curr Sport Med Reports (American Coll Sport Med)*. 2006;5(6):319-322. <http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=23239499&site=ehost-live>.
39. Theologis T. Lever arm dysfunction in cerebral palsy gait. *J Child Orthop*. 2013;7(5):379-382. doi:10.1007/s11832-013-0510-y
40. Kalkman BM, Bar-On L, Cenni F, et al. Achilles tendon moment arm length is smaller in children with cerebral palsy than in typically developing children. *J Biomech*. 2017;56:48-54. doi:10.1016/j.jbiomech.2017.02.027
41. John R. Cameron, James G. Skofronick, Roderick M. Grant JRC. Muscle and Forces. *Phys Body*. 1999:37-84.
42. Sharan D. Recent advances in management of cerebral palsy. *Indian J Pediatr*. 2005;72(11):969-973.
43. Maas JC, Dallmeijer AJ, Huijting P a, et al. Splint: the efficacy of orthotic management in rest to prevent equinus in children with cerebral palsy, a randomised controlled trial. *BMC Pediatr*.

2012;12(1):38. doi:10.1186/1471-2431-12-38

44. Strobl W, Theologis T, Brunner R, et al. Best clinical practice in botulinum toxin treatment for children with cerebral palsy. *Toxins (Basel)*. 2015;7(5):1629-1648. doi:10.3390/toxins7051629
45. Anttila H. *Evidence-Based Perspective on CP Rehabilitation.*; 2008.
46. Abbaskhanian A, Rashedi V, Delpak A, Vameghi R, Gharib M. Rehabilitation Interventions for Children With Cerebral Palsy: A Systematic Review. *J Pediatr Rev*. 2015;3(1). doi:10.5812/jpr.361
47. Condie D, Morris C. *Recent Developments in Healthcare for Cerebral Palsy: Implications and Opportunities for Orthotics.*; 2009.
48. Patel DR. Therapeutic interventions in cerebral palsy. *Indian J Pediatr*. 2005;72(11):979-983. doi:10.1007/BF02731676
49. Aybar A, Parmaksızoğlu A. Overview of Cerebral Palsy and Non-Surgical Treatment Methods. 2012;(November 2012). doi:10.5152/jarem.2012.12
50. Anttila H, Autti-Rämö I, Suoranta J, Mäkelä M, Malmivaara A. Effectiveness of physical therapy interventions for children with cerebral palsy: a systematic review. *BMC Pediatr*. 2008;8:14. doi:10.1186/1471-2431-8-14
51. Damiano DL. Rehabilitative therapies in cerebral palsy: the good, the not as good, and the possible. *J Child Neurol*. 2009;24(9):1200-1204. doi:10.1177/0883073809337919
52. Steultjens EM, Dekker J, Bouter LM, van de Nes JC, Lambregts BL, van den Ende CH. Occupational therapy for children with cerebral palsy: a systematic review. *Clin Rehabil*. 2004;18(1):1-14. doi:10.1191/0269215504cr697oa
53. Pennington L, Goldbart J, Marshall J. Direct speech and language therapy for children with cerebral palsy: findings from a systematic review. *Dev Med Child Neurol*. 2005;47(01):57-63. doi:10.1017/S0012162205000101
54. Hösl M, Böhm H, Arampatzis A, Döderlein L. Effects of ankle-foot braces on medial gastrocnemius morphometrics and gait in children with cerebral palsy. *J Child Orthop*. 2015;9(3):209-219. doi:10.1007/s11832-015-0664-x

55. Ries AJ, Novacheck TF, Schwartz MH. The Efficacy of Ankle-Foot Orthoses on Improving the Gait of Children With Diplegic Cerebral Palsy: A Multiple Outcome Analysis. *PM R*. 2015;7(9):922-929. doi:10.1016/j.pmrj.2015.03.005
56. Bourseul J-S, Lintanf M, Saliou P, Brochard S, Pons C. Effect of ankle-foot orthoses on gait in children with cerebral palsy: A meta-analysis. *Ann Phys Rehabil Med*. 2016;59:e6. doi:10.1016/j.rehab.2016.07.016
57. Abel MF, Juhl GA, Vaughan CL, Damiano DL. Gait assessment of fixed ankle-foot orthoses in children with spastic diplegia. *Arch Phys Med Rehabil*. 1998;79(2):126-133. doi:10.1016/S0003-9993(98)90288-X
58. Damiano DL, Vaughan CL, Abel MF. Muscle response to heavy resistance exercise in children with spastic cerebral palsy. *Dev Med Child Neurol*. 1995;37(8):731-739. <http://www.ncbi.nlm.nih.gov/pubmed/7672470>. Accessed November 6, 2014.
59. Taylor NF, Dodd KJ, Damiano DL. Progressive Resistance Exercise in Physical Therapy : A Summary of. 2005;85(11):1208-1223.
60. Wiley ME, Damiano DL. Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol*. 1998;40(2):100-107. <http://www.ncbi.nlm.nih.gov/pubmed/9489498>. Accessed August 5, 2017.
61. Scholtes V a, Becher JG, Comuth A, Dekkers H, Van Dijk L, Dallmeijer AJ. Effectiveness of functional progressive resistance exercise strength training on muscle strength and mobility in children with cerebral palsy: a randomized controlled trial. *Dev Med Child Neurol*. 2010;52(6):e107-13. doi:10.1111/j.1469-8749.2009.03604.x
62. Scholtes V a, Becher JG, Comuth A, Dekkers H, Van Dijk L, Dallmeijer AJ. Effectiveness of functional progressive resistance exercise strength training on muscle strength and mobility in children with cerebral palsy: a randomized controlled trial. *Dev Med Child Neurol*. 2010;52(6):e107-13. doi:10.1111/j.1469-8749.2009.03604.x
63. Taylor NF, Dodd KJ, Baker RJ, Willoughby K, Thomason P, Graham HK. Progressive resistance training and mobility-related function in young people with cerebral palsy: a randomized controlled trial. *Dev Med Child Neurol*. 2013;55(9):806-812. doi:10.1111/dmcn.12190
64. Damiano DL, Abel MF. Functional outcomes of strength training in spastic cerebral palsy. *Arch*

Phys Med Rehabil. 1998;79(2):119-125. <http://www.ncbi.nlm.nih.gov/pubmed/9473991>. Accessed November 6, 2014.

65. Ross S a, Engsberg JR. Relationships between spasticity, strength, gait, and the GMFM-66 in persons with spastic diplegia cerebral palsy. *Arch Phys Med Rehabil.* 2007;88(9):1114-1120. doi:10.1016/j.apmr.2007.06.011
66. Kruse A, Schranz C, Svehlik M, Tilp M. Mechanical muscle and tendon properties of the plantar flexors are altered even in highly functional children with spastic cerebral palsy. *Clin Biomech.* 2017;50:139-144. doi:10.1016/j.clinbiomech.2017.10.019
67. Damiano DL. Activity, Activity, Activity: Rethinking Our Physical Therapy Approach to Cerebral Palsy. *Phys Ther.* 2006;86(11):1534-1540. doi:10.2522/ptj.20050397
68. Williams MA, Haskell WL, Ades PA, et al. Resistance exercise in individuals with and without cardiovascular disease: 2007 update: A scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation.* 2007;116(5):572-584. doi:10.1161/CIRCULATIONAHA.107.185214
69. Verschuren O, Magnus R, Rehabilitation DH, et al. Exercise and Physical Activity Recommendations for People with Cerebral Palsy. 2016;58(8):798-808. doi:10.1111/dmcn.13053.Exercise
70. Behm DG, Faigenbaum AD, Falk B, Klentrou P. Canadian Society for Exercise Physiology position paper: resistance training in children and adolescents. *Appl Physiol Nutr Metab.* 2008;33(3):547-561. doi:10.1139/H08-020
71. Dodd KJ, Taylor NF, Damiano DL. A systematic review of the effectiveness of strength-training programs for people with cerebral palsy. *Arch Phys Med Rehabil.* 2002;83(8):1157-1164. doi:10.1053/apmr.2002.34286
72. Taylor NF, Dodd KJ, Baker RJ, Willoughby K, Thomason P, Graham HK. Progressive resistance training and mobility-related function in young people with cerebral palsy: a randomized controlled trial. *Dev Med Child Neurol.* 2013;55(9):806-812. doi:10.1111/dmcn.12190
73. Aagaard P. *Training-Induced Changes in Neural Function.* Vol 31.; 2003. doi:10.1097/00003677-200304000-00002

74. Noelle G. Moreau, PhD, PT, Michael Falvo, PhD, and Diane L. Damiano, PhD P. Rapid Force Generation is Impaired in Cerebral Palsy and is Related to Decreased Muscle Size and Functional Mobility. *Gait Posture*. 2013;35(1):154-158.
doi:10.1016/j.gaitpost.2011.08.027.Rapid
75. Cassidy S, Thoma C, Houghton D, Trenell MI. High-intensity interval training: a review of its impact on glucose control and cardiometabolic health. *Diabetologia*. 2017;60(1):7-23.
doi:10.1007/s00125-016-4106-1
76. Angadi SS, Mookadam F, Lee CD, Tucker WJ, Haykowsky MJ, Gaesser GA. High-intensity interval training vs. moderate-intensity continuous exercise training in heart failure with preserved ejection fraction: a pilot study. *J Appl Physiol*. 2015;119(6):753-758.
doi:10.1152/jappphysiol.00518.2014
77. Laursen PB, Jenkins DG. The scientific basis for high intensity interval training - optimising training programmes and maximising performance in highly trained endurance athletes. *Sport Med*. 2002;32(1):52-73.
78. García-Pinillos F, Soto-Hermoso VM, Latorre-Román PA. How does high-intensity intermittent training affect recreational endurance runners? Acute and chronic adaptations: A systematic review. *J Sport Heal Sci*. 2017;6(1):54-67. doi:10.1016/j.jshs.2016.08.010
79. Salazar-Martínez E, Santalla A, Orellana JN, Strobl J, Burtscher M, Menz V. Influence of high-intensity interval training on ventilatory efficiency in trained athletes. *Respir Physiol Neurobiol*. 2018;250(November 2017):19-23. doi:10.1016/j.resp.2018.01.016
80. Ross LM, Porter RR, Durstine JL. High-intensity interval training (HIIT) for patients with chronic diseases. *J Sport Heal Sci*. 2016;5(2):139-144. doi:10.1016/j.jshs.2016.04.005
81. Cockcroft EJ, Moudiotis C, Kitchen J, Bond B, Williams CA, Barker AR. High-intensity interval exercise and glycemic control in adolescents with type one diabetes mellitus: a case study. *Physiol Rep*. 2017;5(13):1-6. doi:10.14814/phy2.13339
82. Kao S-C, Drollette ES, Ritondale JP, Khan N, Hillman CH. The acute effects of high-intensity interval training and moderate-intensity continuous exercise on declarative memory and inhibitory control. *Psychol Sport Exerc*. 2018;38(May):90-99.
doi:10.1016/J.PSYCHSPORT.2018.05.011

83. Torabi F, Farahani A, Safakish S, Ramezankhani A, Dehghan F. Evaluation of motor proficiency and adiponectin in adolescent students with attention deficit hyperactivity disorder after high-intensity intermittent training. *Psychiatry Res.* 2018;261(January 2017):40-44. doi:10.1016/j.psychres.2017.12.053
84. Schmitz B, Nelis P, Rolfes F, et al. Effects of high-intensity interval training on optic nerve head and macular perfusion using optical coherence tomography angiography in healthy adults. *Atherosclerosis.* 2018;274:8-15. doi:10.1016/j.atherosclerosis.2018.04.028
85. Lauglo R, Vik T, Lamvik T, Stensvold D, Finbråten A-K, Moholdt T. High-intensity interval training to improve fitness in children with cerebral palsy. *BMJ Open Sport Exerc Med.* 2016;2(1):e000111. doi:10.1136/bmjsem-2016-000111
86. Sperlich B, Zinner C, Heilemann I, Kjendlie P-L, Holmberg H-C, Mester J. High-intensity interval training improves VO₂peak, maximal lactate accumulation, time trial and competition performance in 9-11-year-old swimmers. *Eur J Appl Physiol.* 2010;110(5):1029-1036. doi:10.1007/s00421-010-1586-4
87. Kostanjsek N. Use of The International Classification of Functioning , Disability and Health (ICF) as a conceptual framework and common language for disability statistics and health information systems. *BMC Public Health.* 2011;11(Suppl 4):S3. doi:10.1186/1471-2458-11-S4-S3
88. Lauglo R, Vik T, Lamvik T, Stensvold D, Finbråten A-K, Moholdt T. High-intensity interval training to improve fitness in children with cerebral palsy. *BMJ Open Sport Exerc Med.* 2016;2(1):e000111. doi:10.1136/bmjsem-2016-000111
89. Van Vulpen LF, De Groot S, Rameckers E, Becher JG, Dallmeijer AJ. Improved Walking Capacity and Muscle Strength after Functional Power-Training in Young Children with Cerebral Palsy. *Neurorehabil Neural Repair.* 2017;31(9):827-841. doi:10.1177/1545968317723750
90. Novak I, McIntyre S, Morgan C, et al. A systematic review of interventions for children with cerebral palsy: State of the evidence. *Dev Med Child Neurol.* 2013;55(10):885-910. doi:10.1111/dmcn.12246
91. Lorentzen J, Greve LZ, Kliim-Due M, Rasmussen B, Bilde PE, Nielsen JB. Twenty weeks of home-based interactive training of children with cerebral palsy improves functional abilities. *BMC*

Neurol. 2015;15:75. doi:10.1186/s12883-015-0334-0

92. Chen CL, Chen CY, Liaw MY, Chung CY, Wang CJ, Hong WH. Efficacy of home-based virtual cycling training on bone mineral density in ambulatory children with cerebral palsy. *Osteoporos Int.* 2013;24(4):1399-1406. doi:10.1007/s00198-012-2137-0
93. Sgandurra G, Cecchi F, Beani E, et al. Tele-UPCAT: Study protocol of a randomised controlled trial of a home-based Tele-monitored UPper limb Children Action observation Training for participants with unilateral cerebral palsy. *BMJ Open.* 2018;8(5):1-12. doi:10.1136/bmjopen-2017-017819
94. Mattern-Baxter K, McNeil S, Mansoor JK. Effects of Home-Based Locomotor Treadmill Training on Gross Motor Function in Young Children With Cerebral Palsy: A Quasi-Randomized Controlled Trial. *Arch Phys Med Rehabil.* 2013;94(11):2061-2067. doi:10.1016/j.apmr.2013.05.012
95. Chen K, Wu Y-N, Ren Y, et al. Home-Based Versus Laboratory-Based Robotic Ankle Training for Children With Cerebral Palsy: A Pilot Randomized Comparative Trial. *Arch Phys Med Rehabil.* 2016;97(8):1237-1243. doi:10.1016/j.apmr.2016.01.029
96. Reedman SE, Boyd RN, Elliott C, Sakzewski L. ParticiPAte CP: A protocol of a randomised waitlist controlled trial of a motivational and behaviour change therapy intervention to increase physical activity through meaningful participation in children with cerebral palsy. *BMJ Open.* 2017;7(8):1-15. doi:10.1136/bmjopen-2017-015918
97. Dodd KJ, Taylor NF, Damiano DL. A systematic review of the effectiveness of strength-training programs for people with cerebral palsy. *Arch Phys Med Rehabil.* 2002;83(8):1157-1164. <http://www.ncbi.nlm.nih.gov/pubmed/12161840>. Accessed November 3, 2014.
98. Centers for Disease Control and Prevention (CDC). Economic costs associated with mental retardation, cerebral palsy, hearing loss, and vision impairment--United States, 2003. *MMWR Morb Mortal Wkly Rep.* 2004;53(3):57-59. <http://www.ncbi.nlm.nih.gov/pubmed/14749614>. Accessed July 7, 2018.
99. Jansons P, Robins L, O'Brien L, Haines T. Gym-based exercise was more costly compared with home-based exercise with telephone support when used as maintenance programs for adults with chronic health conditions: cost-effectiveness analysis of a randomised trial. *J Physiother.*

2018;64(1):48-54. doi:10.1016/j.jphys.2017.11.010

100. Verschuren O, Ketelaar M, Takken T, Van Brussel M, Helders PJM, Gorter JW. Reliability of hand-held dynamometry and functional strength tests for the lower extremity in children with Cerebral Palsy. *Disabil Rehabil.* 2008;30(18):1358-1366. doi:10.1080/09638280701639873
101. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther.* 1987;67(2):206-207. <http://www.ncbi.nlm.nih.gov/pubmed/3809245>. Accessed November 16, 2014.
102. Baker R, McGinley JL, Schwartz MH, et al. The Gait Profile Score and Movement Analysis Profile. *Gait Posture.* 2009;30(3):265-269.
103. Steenman K, Verschuren O, Rameckers E, Douma-van Riet D, Takken T. Extended Reference Values for the Muscle Power Sprint test in 6-to 18-Year-Old Children. *Pediatr Phys Ther.* 2016;28(1):78-84. doi:10.1097/PEP.0000000000000209
104. Romeiser Logan L. Children with cerebral palsy are just like everyone else: What you train is what you get. *Dev Med Child Neurol.* 2013;55(9):777. doi:10.1111/dmcn.12211
105. Boyd RN. Functional progressive resistance training improves muscle strength but not walking ability in children with cerebral palsy. *J Physiother.* 2012;58(3):197. doi:10.1016/S1836-9553(12)70111-X
106. Radtka S, Hone R, Brown C, Mastick J, Melnick ME, Dowling GA. Feasibility of Computer-Based Videogame Therapy for Children with Cerebral Palsy. *Games Health J.* 2013;2(4):222-228. doi:10.1089/g4h.2012.0071
107. Scholtes V a, Dallmeijer AJ, Rameckers E a, et al. Lower limb strength training in children with cerebral palsy--a randomized controlled trial protocol for functional strength training based on progressive resistance exercise principles. *BMC Pediatr.* 2008;8:41. doi:10.1186/1471-2431-8-41
108. Buford TW, Roberts MD, Church TS. Toward exercise as personalized medicine. *Sports Med.* 2013;43(3):157-165. doi:10.1007/s40279-013-0018-0
109. Diaz Heijtz R, Almeida R, Eliasson AC, Forssberg H. Genetic Variation in the Dopamine System Influences Intervention Outcome in Children with Cerebral Palsy. *EBioMedicine.* 2018;28:162-

167. doi:10.1016/j.ebiom.2017.12.028
110. Trovato F, Imbesi R, Conway N, Castrogiovanni P. Morphological and Functional Aspects of Human Skeletal Muscle. *J Funct Morphol Kinesiol*. 2016;1(3):289-302.
doi:10.3390/jfmk1030289
111. Hopkins PM. Skeletal muscle physiology. *Contin Educ Anaesthesia, Crit Care Pain*. 2006;6(1):1-6. doi:10.1093/bjaceaccp/mki062
112. Lieber RL, Fridén I. Skeletal muscle and tendon microanatomy. *Curr Opin Orthop*. 1991;2:691-695.
113. Lieber RL. *Skeletal Muscle Structure, Function, and Plasticity*.; 2011.
doi:10.1016/j.physb.2006.10.039
114. Seene T, Kaasik P. Skeletal Muscle Adaptation to Endurance Exercise : Fibre Type Peculiarities. *Austin Sport Med*. 2017;2(2).
115. Laspers J. The Muscular System — Skeletal Muscle Tissue and Organization. *Muscular Syst — Skelet Muscle Tissue Organ*. 2009:2-48.
http://www.napavalley.edu/people/briddell/Documents/BIO_218/09_LectureOutline.pdf.
116. Taylor NF. Is progressive resistance exercise ineffective in increasing muscle strength in young people with cerebral palsy? *Aust J Physiother*. 2009;55(3):222; author reply 223.
<http://www.ncbi.nlm.nih.gov/pubmed/19681747>.
117. Damiano DL, Quinlivan J, Owen BF, Shaffrey M, Abel MF. Spasticity versus strength in cerebral palsy: relationships among involuntary resistance, voluntary torque, and motor function. *Eur J Neurol*. 2001;8(s5):40-49. doi:10.1046/j.1468-1331.2001.00037.x
118. Physio JCM, Galea MP. Hand-held dynamometry for muscle strength measurement in children with cerebral palsy. 2007:106-111.
119. Diane L Damiano, Neurological A. Should we be testing and training muscle strength in cerebral palsy ? 2002:68-72.
120. Verschuren O, Takken T, Ketelaar M, Gorter JW, Helders PJM. Reliability for running tests for measuring agility and anaerobic muscle power in children and adolescents with cerebral palsy. *Pediatr Phys Ther*. 2007;19(2):108-115. doi:10.1097/pep.0b013e318036bfce

121. Verschuren O, Bloemen M, Kruitwagen C, Takken T. Reference values for anaerobic performance and agility in ambulatory children and adolescents with cerebral palsy. *Dev Med Child Neurol.* 2010;52(10):e222-8. doi:10.1111/j.1469-8749.2010.03747.x
122. Verschuren O, Bongers BC, Obeid J, Ruyten T, Takken T. Validity of the Muscle Power Sprint test in ambulatory youth with cerebral palsy. *Pediatr Phys Ther.* 2013;25(1):25-28. doi:10.1097/PEP.0b013e3182791459
123. Nsenga Leunkeu A, Shephard RJ, Ahmaidi S. Six-minute walk test in children with cerebral palsy gross motor function classification system levels i and II: Reproducibility, validity, and training effects. *Arch Phys Med Rehabil.* 2012;93(12):2333-2339. doi:10.1016/j.apmr.2012.06.005
124. Guyatt GH, Townsend M, Keller J, Singer J, Nogradi S. Measuring functional status in chronic lung disease: conclusions from a randomized control trial. *Respir Med.* 1991;85 Suppl B:17-21; discussion 33-7. <http://www.ncbi.nlm.nih.gov/pubmed/1759016>. Accessed August 6, 2017.
125. Maher CA, Williams MT, Olds TS. The six-minute walk test for children with cerebral palsy. *Int J Rehabil Res.* 2008;31(2):185-188. doi:10.1097/MRR.0b013e32830150f9
126. Nicolini-Panisson RD, Donadio MVF. Timed "Up & Go" test in children and adolescents. *Rev Paul Pediatr.* 2013;31(3):377-383. doi:10.1590/S0103-05822013000300016
127. Williams EN, Carroll SG, Reddihough DS, Phillips BA, Galea MP. Investigation of the timed "up & go" test in children. *Dev Med Child Neurol.* 2005;47(8):518-524. <http://www.ncbi.nlm.nih.gov/pubmed/16108451>. Accessed November 7, 2014.
128. Zaino CA, Marchese VG, Westcott SL. Timed up and down stairs test: preliminary reliability and validity of a new measure of functional mobility. *Pediatr Phys Ther.* 2004;16(2):90-98. doi:10.1097/01.PEP.0000127564.08922.6A
129. Dhote SN, Khatri PA, Ganvir SS. Reliability of "Modified timed up-and-go" test in children with cerebral palsy. *J Pediatr Neurosci.* 2012;7(2):96-100. doi:10.4103/1817-1745.102564
130. Andersson C, Grooten W, Hellsten M, Kaping K, Mattsson E. Adults with cerebral palsy: walking ability after progressive strength training. *Dev Med Child Neurol.* 2003;45(2003):220-228. doi:10.1017/S0012162203000446

131. Armand S, Decoulon G, Bonnefoy-Mazure A. Gait analysis in children with cerebral palsy. *EFORT Open Rev.* 2016;1(12):448-460. doi:10.1302/2058-5241.1.000052
132. Rozkalne Z, Bertule D. Measurement of activities and participation for children with cerebral palsy: A systematic review. *SHS Web Conf.* 2014;10(00038). doi:10.1051/shsconf/20141000038
133. Young NL, Williams JI, Yoshida KK, Wright JG. Measurement properties of the Activities Scale for Kids. 2000;53:125-137.
134. Bagley AM, Gorton GE, Bjornson K, et al. Factor- and item-level analyses of the 38-item Activities Scale for Kids – performance. 2010:161-166. doi:10.1111/j.1469-8749.2010.03797.x
135. Young NL, Varni JW, Snider L, et al. The Internet is valid and reliable for child-report: An example using the Activities Scale for Kids (ASK) and the Pediatric Quality of Life Inventory (PedsQL). *J Clin Epidemiol.* 2009;62(3):314-320. doi:10.1016/j.jclinepi.2008.06.011
136. Moreau NG, Simpson KN, Teefey SA, Damiano DL. Muscle architecture predicts maximum strength and is related to activity levels in cerebral palsy. *Phys Ther.* 2010;90(11):1619-1630. doi:10.2522/ptj.20090377
137. Daltroy LH, Liang MH, Fossel AH, Goldberg MJ. The POSNA pediatric musculoskeletal functional health questionnaire: report on reliability, validity, and sensitivity to change. Pediatric Outcomes Instrument Development Group. Pediatric Orthopaedic Society of North America. *J Pediatr Orthop.* 18(5):561-571. <http://www.ncbi.nlm.nih.gov/pubmed/9746401>. Accessed December 10, 2017.
138. Allen DD, Gorton GE, Oeffinger DJ, Tylkowski C, Tucker CA, Haley SM. Analysis of the Pediatric Outcomes Data Collection Instrument (PODCI) in Ambulatory Children with Cerebral Palsy Using Confirmatory Factor Analysis and Item Response Theory Methods. *J Pediatr.* 2008;28(2):192-198. doi:10.1097/BPO.0b013e3181652185.Analysis
139. Fowler EG, Kolobe TH, Damiano DL, et al. Promotion of physical fitness and prevention of secondary conditions for children with cerebral palsy: section on pediatrics research summit proceedings. *Phys Ther.* 2007;87(11):1495-1510. doi:10.2522/ptj.20060116