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Coupling Timing of interventions with Dose to Optimize Plasticity and Participation in Pediatric Neurologic Populations

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Abstract

The purpose of this paper is to propose that coupling of timing of interventions with dosing of interventions optimizes plasticity and participation in pediatric neurologic conditions, specifically cerebral palsy. Dosing includes frequency, intensity, time per session, and type of intervention. Interventions focus on body structures and function and activity and participation, and both are explored. Known parameters for promoting bone, muscle, and brain plasticity and evidence supporting critical periods of growth during development are reviewed. Although parameters for dosing participation are not yet established, emerging evidence suggests participation at high intensities has the potential for change. Participation interventions may provide an additional avenue to promote change through the life span. Recommendations for research and clinical practice are presented to stimulate discussions and innovations in research and practice.

Keywords

cerebral palsy; dose; critical periods; participation; plasticity

INTRODUCTION

Optimizing plasticity and participation of pediatric populations with neurologic conditions is aligned with the profession's vision to "transform society by optimizing movement".¹ To enact this vision, education at the doctorate level provides us with skills to be evidence based practitioners, clinician-researchers, advocates, and community leaders. Determining treatment effectiveness for pediatric populations with neurologic conditions is a priority identified by the Institute of Medicine² and by pediatric physical therapists.³ It is a complex problem with many factors.⁴ Our knowledge of children, families, environment, development, and interventions can inform practice and research.^{3, 5, 6} Dose is operationally defined by its parameters: 1) frequency; the number of sessions a week and number of weeks; (2) intensity; strenuousness of exercise; (3) time per session; and (4) the type of intervention.⁷ Type of intervention refers to the focus of the intervention, for example, changing body structures and function, or activity and participation. Critical periods of plasticity reinforce the importance of age of intervention, that is, the timing of the

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intervention. The challenge is to integrate knowledge about the effective dose (frequency, intensity, and time per session) given the different types of interventions with attention to the optimal timing of interventions to maximize plasticity and participation.

The optimal dose of an intervention ideally produces sustainable changes at the level of body structures and function and activity and participation.⁴ Determining the optimal dose given a child's individual, family, and community characteristics is a national priority for the Federal Government,⁸ third party payers, school districts, pediatricians, rehabilitation centers, therapists, and the children.² Development of practice guidelines that promote optimal outcomes (satisfaction, function, health, participation) and minimize costs to families, society, the individual, and the providers are needed.^{4, 9}

Interventions cannot be optimally dosed if there is no evidence of demonstrated effectiveness at either the structural or functional level. Effective interventions are "worth it"¹⁰ if the effort yields positive short and long-term outcomes. We have previously described a path model for dosing⁴ pediatric rehabilitation services (Figure 1), and moderating and mediating factors of treatment effectiveness. Dose is a factor that can be modified. Exercise dosing includes the type of intervention, frequency, intensity, and time per session. Regardless of type, the time per session, effort, and frequency of performance of an activity appear to be a key factors.³ Age is a moderating factor; and optimizing timing of interventions, or age at intervention, has potential to improve treatment effectiveness. Interventions may have the greatest effect when harnessing the increased potential for plastic changes during critical periods of brain, bone, and muscle development. Moreover, activity based and participation interventions have the potential to increase dose in the natural environment, and if dosed high enough may yield changes.¹¹ Combining the two factors of dose and timing of interventions may open new pathways for promoting positive outcomes.

The path model for dosing (Figure 1) classifies type of intervention according to the International Classification of Functioning, Health, and Disability (ICF). These classifications are impairments, activity limitations, or participation restrictions.^{4, 12} Type of intervention also refers to the specific physiological mechanisms by which the intervention creates change, e.g., muscle hypertrophy, motor learning, increased trabecular bone formation, or increased movement or engagement in everyday life. Types of interventions can be at the level of body structures and function and plasticity supported (changes in muscle, bone, or brain); at the level of activity and participation (changes in movement and interaction with the environment) and participation driven, or both. The differential impact of optimal type of intervention is explored with recommendations for research and clinical practice.

COUPLING TIMING AND DOSE

Dose is important in determining the effectiveness of pediatric rehabilitation interventions. Interventions at the body structures level may affect changes at the level of body structures and function and link to performance in everyday life (Figure 2). Interventions at the activity and participation level may affect changes in performance capacity and in everyday life and capacity with changes in structure and function. Age at time of interventions moderates

outcomes. Optimal timing of interventions has the potential to increase treatment effectiveness.

Dosing parameters for interventions focused on body structures and function and activity and participation are described below. For each type of each of intervention described, evidence for effective frequency, intensity, and time per session are reviewed. Evidence is given to support optimal timing or age at intervention. Tables 1 and 2 summarize interrelationships among factors that mediate and moderate interventions that capitalize on the plasticity of the musculoskeletal system of the central nervous system or those that increase participation in daily life to create structural and functional change

Interventions that Harness Plasticity to Create Change

Improving Bone Structure and Function—There are interventions that optimize skeletal development during critical periods in early infancy and pre-puberty. Most of the fetal bone accrual occurs in the last trimester of pregnancy and is dependent on movement.¹³ Newborns with limited movement in utero have smaller, weaker bones and are at greater risk for fracture.^{14, 15} Spontaneous movement or the lack of activity is associated with bone strength in healthy infants and very low birth weight infants with unilateral brain insults.¹⁶ Infants who are born prematurely may have fewer opportunities for movement during the first few weeks of life during hospitalization as compared to infants who are born full term and are able to move in utero.¹⁷ Evidence supports passive, flexion and extension range of motion exercises of the upper and lower extremities in preterm infants, 10 minutes for 4–8 weeks, with an increased effect after 8 weeks¹⁷ to positively impact bone health.

Growth hormones facilitate bone modeling that occurs pre puberty and during puberty. Adolescents accumulate 25% of their adult bone during the 2–3 years after maximal height is reached, on average 13.4 years for boys, and 11.8 for girls.^{18–20} Interventions provided before maximal height is reached may provide the greatest treatment effect.²⁰ Interventions for bone during in childhood may provide a lifetime of benefit.²⁰

Dose: For typically developing children, a systematic review of randomized controlled trials of Key factors for exercise interventions to improve bone health for children developing typically are frequency and duration of the activity, loading on the skeleton during the activity, and age at the time of activity.²¹ For activities with lower loading on the skeleton, increasing the frequency of the activity within a session or during the week can increase osteogenic potential.²² The osteogenic index of an exercise is calculated as: (intensity * ln [frequency + 1] * times per week).²² An example of an exercise intervention that was effective immediately, after 3 and after 8 years with healthy pre-pubertal children required children to jump high enough for a ground reaction force 8 times their body weight, 100 times (10 minutes), 3 times a week, for 7 months.²³ This yielded an osteogenic index of 110. For children who cannot perform activities that produce a ground reaction force of 8 times their body weight (jumping off a 60 cm box), but can produce a ground reaction force 2 times their body weight, an osteogenic index of 110–115 can be obtained by increasing the number of loading cycles to 1200 and the frequency to 9 episodes per week. Bone requires about 8 to 10 hours rest, so a frequency of twice a day bone loading is possible.²²

Bone health should be monitored in children with CP,^{24, 25} however, there is no consensus for dosing exercise interventions.²⁴ In a systematic review, Novak¹⁰ identifies a “worth it” line of interventions for children with CP. Whole body vibration (WBV) is on the line of just being “worth it”, and standing frames are closer to “probably do it”.¹⁰ Bone response to skeletal loading in children with CP appears to be more positive when standing programs are performed frequently and for a long duration (3 times a week for 9 months).^{26, 27} Dynamic standers may have increased effect on bone in children with severe CP as compared to static standers.^{28–30} Multimodal programs that include aquatics, body weight support (BWS) treadmill training, and progressive resistive exercises have evidence of effectiveness for children Gross Motor Functional Classification System (GMFCS) levels I–IV.^{31, 32} Whole body vibration (WBV) tends to increase bone in the tibial plateau,³³ cycling and standing exercise may increase bone in the distal femur.^{31, 34} Vibrating pads placed on long bones while children are sitting in chairs have demonstrated some effect on bone.³⁵ Insufficient evidence exists to support any of the types of bone interventions for prevention of spinal and hip deformity into adulthood.^{36, 37}

Improving Muscle Structure and Function—Interventions for muscle are generally focused on improving joint range of motion or muscle performance including strength and power.

Timing for Change in Muscle: Muscles are highly plastic, and responsive to activity or inactivity.³⁸ Development of muscle architecture is closely connected to the development of the spinal central pattern generators, corticospinal development, motor unit formation, and motor activation patterns from early fetal development, through infancy and early childhood.³⁹ Activity refines both systems,³⁹ including cell differentiation (e.g., muscle fibers from Type I to Type 2, nerve cell types), maturation of cells, and epigenetic transcription.^{38, 40} Dotan⁴¹ argues a complex interrelationship among a muscle’s metabolic profile, muscle structure, fiber composition, and the cortical impulses directing firing of motor units, accounts for differences in muscle performance between adults and children. Both the muscle and its relationship with the motor unit create differences in activation patterns. Muscles develop in response to interaction with their neurophysiological environment⁴¹ and differences are present in infants with early brain injury.⁴⁸

Evidence suggests that “critical muscle symptoms” begin early in life. Infants with brain injury spontaneously kick fewer times, at slower velocity, and within a more constrained range of movement than age matched peers without brain injury.⁴² A study of infants born preterm and full term correlated magnetic resonance spectroscopy metabolic findings (indicating brain injury) with kinematic measures of infant motor performance, specifically greater knee flexion and plantar flexion in standing.⁴³ Additionally, infants at high risk for CP had less musculo-tendinous extensibility and cross sectional area of ankle musculature at 6 and 12 weeks corrected gestational age compared to infants at low risk, indicating muscular architectural differences may occur much earlier than previously thought in infants at high risk for CP.⁴⁴

Children who develop CP may have moved less in utero,¹³ and because of prematurity, had less time to move in utero, moved less as infants,⁴² and as children, moved less than peers.⁴⁵

The lack of activity during these critical periods of muscle development may also predispose children with CP to metabolic disease, fatty infiltrate in muscle, early onset sarcopenia,⁴⁶ and negative consequences for diseases of aging.⁴⁷

Self initiated movement⁴⁸ in infancy combined with active assistive and passive movements that are developmentally appropriate^{17, 49} take advantage of plasticity in muscle structure, motor unit, and corticospinal tracts during this time and may influence genetic transcription for later in life.³⁸ Promotion of muscle activation and muscle performance should continue throughout life, and become more aggressive at about age 5 years. Resistance training can begin as early as age 5.⁵⁰ Training rate of force development has potential for increasing gait speed⁵¹ or reaching⁵² by promoting changes in muscle structures. Training at the structural level to increase performance at earlier ages has the potential for an increased treatment effect. Changes in movement activity, gait speed or reaching, may sustain changes at the structural level of the muscle. Maintaining muscle volume and strength across the lifespan requires a regular exercise program.⁵³

Dosing Joint Range of Motion: Range of motion in children with CP decreases with age.⁵⁴ Reviews of physiological and clinical studies^{55–57} suggest that manual resistance is not effective for maintaining or improving range of motion.⁵⁸ Stretching prior to strengthening activities is not recommended by the National College of Strength and Conditioning for youth adults as it reduces the ability of the muscle to generate force as the tendon and sarcomeres become over-lengthened, although a dynamic warm-up is recommended.^{52, 59} Evidence supports that although CP is a brain injury, “critical symptoms”^{38, 60} appear in the muscle including: change in muscle sarcomere length, fiber type, extracellular concentration, fiber and fiber bundle stiffness, reduced stem cell numbers, and epigenetic transcription that may perpetuate these traits.

Interventions that focus on changing pathology in muscle structures may provide new avenues for treatment.^{38, 60} Combined active and passive movement (using a robotic device) 3–5 times a week for 30 minutes for 6 or more weeks produced positive structure-function outcomes. Participants obtained increased range of motion, decreased spasticity,⁴⁹ elongated muscle fascicles, reduced muscle pennation angle, reduced fascicular stiffness, decreased tendon length, and increased Achilles tendon stiffness.^{49, 61}

Prolonged positioning is effective at a dose of 3–5 times per week for more than 30 min for at least 9 months.⁵⁵ Positioning links structure, in terms of joint motion and function. Yet, it is unclear as to the mechanism on the structural level.⁵⁵ The over-lengthened tendons and sarcomeres may be elongating such that the muscle is more inefficient^{55, 57} Joint range of motion is enhanced by changes in movement activity such as rock climbing, horseback riding, bike riding, soccer.

Dosing Muscle performance: Children with CP gain muscle strength by performing open chain progressive resistive exercise, use of functional electric stimulation, loaded sit to stand or functional training and velocity training using a total gym or isokinetic dynamometer.^{62, 63} Despite moderate increases in strength, there is no evidence to support that resistance training improves walking speed⁶⁴ or changes in gross motor function.⁶⁵ One

study demonstrates resistance and velocity training both increase strength, but only velocity training produced positive changes in muscle architecture and gait speed.⁵¹ Insufficient dose is common for resistance programs for children with CP and using parameters established by the National Strength and Conditioning Association is recommended.^{52, 66}

Participation Driven Interventions—Activity based interventions such as reaching training and locomotion training use plasticity of body structures and function to improve activity and participation. Evidence to support the activity dependency of cortico-spinal projections and the development of spinal motor neurons suggests that lack of activity has a pervasively negative impact on the nervous system.^{39, 67, 68} Theories of motor learning⁷¹ and motor control^{69, 70} with evidence for neuroplasticity^{71–74} guide interventions designed to improve motor control, and place the focus on plasticity of the central nervous system as the mechanism for improving motor control and function. Plasticity of musculoskeletal and cardiorespiratory systems may also contribute to changes.

Timing for Plasticity of the Central Nervous System: Although brain plasticity is present throughout life,⁷⁵ “early in development there may be a critical period in which the brain possesses high capacity for reorganization to compensate for injury and the extent of this period is still unknown”.^{76 p.6} This critical period has not been identified, but it the period immediately after injury is important. Friel et al.⁷⁷ used an animal model to demonstrate the effects of reaching training with constraint of uninjured side to remediate motor function after developmental injury; early intervention recipients had a greater treatment response.

Pre reaching behaviors and the development of reaching behaviors in infants who are preterm and high risk are distinguished by lack of movement, speed, and asymmetry.^{78–80} Intervention early in life⁸¹ has potential for improving reaching behaviors mitigating the consequences of loss of exploration and interaction experienced by infants with poor reaching.

The reciprocal movements of the lower extremities are present at infancy and forward locomotion begins around the first year of life.⁸² Infant kicking provides opportunities for decoupling extremities, producing variability in movement patterns and developing speed of movement.⁸² Walking experience is critical to learning to walk.⁸³ Early locomotion using BWS accelerates walking in children with Down’s syndrome,⁸⁴ and for a child with spinal cord injury has resulted in recovery of walking abilities.⁸⁵ The critical period for optimizing gait is not clear for children with brain injury, although precursor movements occur early in life. Gait speed decreases with age in children with CP,⁸⁶ and adults with CP often stop walking because of pain and fatigue.^{87, 88} Hence, locomotion training may be impactful across the lifespan.

Dosing Reaching Training for Changes in Participation: Reaching training is effective in changing motor abilities for both bimanual activities and modified constraint induced therapy.⁸⁹ A key component of effectiveness appears to be time, with a recommendation of more than 90 hours of practice.⁸⁹ Changes in brain structure and function (e.g., diffuse tensor imaging changes in corticospinal tracts, changes in activation of motor cortex) have been demonstrated with changes in reaching abilities.^{90, 91} However, the association of changes in

reaching abilities and participation or performance in everyday life, is not clear.⁹² Contextual factors may shape participation regardless of changes in activity level. The essential components of effectiveness of reaching training to create changes in the central nervous system and in motor abilities are intensity of practice, the number of repetitions, the time per session, and the engagement of the child.⁸⁹

Dosing Locomotion Training for Changes in Participation: A systematic review of interventions to improve gait speed, confirm the effectiveness of gait training, whether over-ground or using body weight support (BWS).⁶⁴ The interventions have similar effectiveness,⁹³ although there is a trend for greater effect sizes in studies with over-ground training.⁶⁴ Studies with locomotion training that occurred at a frequency of at least twice a week, for 30 minutes, for greater than 9 weeks had the largest effect sizes.⁶⁴ Results of several studies report changes at the level of body structures and function, including improved endurance,^{94–97} reduced ankle stiffness,⁹⁷, increased H-reflex latency,⁹⁸ and improved gait kinematics.⁹⁹ One investigation used coherence of EMG analysis as a way of measuring and detecting changes in the output of the motor cortex and its transmission to the spinal cord through the corticospinal tract during functional muscle activation. There was improved EMG-EMG coherence of anterior tibialis motor neurons of children with CP after training on an incline treadmill 30 min for 30 days consecutively.¹⁰⁰ Evidence to link locomotion training with changes the central nervous system structure and function are scarce. Maintaining gains from locomotion training requires changes in everyday performance, and little evidence exists to support changes in participation with changes in locomotion abilities. The optimal dose is unclear for locomotion training to obtain changes in activity, body structures and function and participation.

Participation Interventions—Participation interventions, or context-based interventions, are those interventions that change the task or the environment, and do not change the impairments of the child.¹⁰¹ In the path model (Figures 1&3), community and environment influence dose. Environmental modifications can provide additional opportunities for movement. If movement is repeated, there is the potential for changes in body structures and function, for example to brain, muscle, or bone. Context-based interventions can provide more time for practice, more engagement, and movement that is self-initiated, all features that promote change. Interventions occur in the home, school, or community, occurring outside of a therapy session.

Timing for Participation Interventions: Optimal timing for participation interventions appears to be immediately after birth and throughout lifespan. Evidence supports the importance of interaction with the environment for optimal development of cognitive, social, emotional, visual, perceptual, and motor skills during childhood.^{102, 103} Descriptions of typical and atypical mobility and visuo-spatial development of infants,¹⁰⁴ typical toddler movements in a room, typical infant movements throughout the day,¹⁰⁵ and children's¹⁰⁶ and adult's spatial movement patterns in their homes and communities will inform both timing and dose. Understanding the disparity found in time, quality, and space of individual environmental interactions can inform the amount and ages for participation interventions

and may yield sustainable changes in activity and participation and body structures and function.

Dosing Participation Interventions to Create Change: The evidence to support an optimal dose for participation-based interventions is not clear. A randomized controlled trial demonstrated that context-based interventions are at least as effective as impairment-based interventions in improving participation. The authors suggested that perhaps the interventions were under-dosed.¹⁰⁷ Although optimal dose of participation interventions is not known, interventions that provide more time for practice have potential for driving sustainable change. Technology can provide new opportunities for participation. A modified toy car for mobility in the home for children who are not ambulatory¹⁰⁸ provides a high frequency of child-environment interaction and a high level of engagement. A suspension harnesses can allow toddlers and children with mobility challenges the opportunity to safely explore their environment.¹⁰⁹ A self initiated prone scooter assists infants with floor mobility¹¹⁰ and allows exploration. Micro-sensors on infants' lower extremities can activate crib mobiles and provide opportunities to improve lower extremity movement patterns.⁴⁸ Contextual interventions can be provided throughout the day, and infants, children, and adults can spend more time practicing. How much practice is enough to elicit changes is still unknown.

PRIORITIES FOR RESEARCH

Six priorities for research are described that have the potential to impact clinical practice in the next decade.

Dosing Participation Interventions

For pediatric physical therapists to design effective interventions, which utilize participation driven interventions, more information is needed about the dose of a particular participation intervention needed to change either participation of the individual, body structures and function, or both. What is typical participation across developmental ages and activities? Descriptive longitudinal studies of participation of children, or interaction of infants and children with and within their environment are needed as baseline reference values of typical child behavior across geographic regions and socio-cultural groups. We need a greater understanding of the mobility patterns of children and adolescents in their homes, schools and communities. More information is needed on typical infant spontaneous leg and arm movements. We need a greater understanding of the physical exploration of toddlers of their environment.

What are the logistics of dosing participation at high intensities? If high-risk infants and children require sophisticated technology for participation interventions, can low cost technology do the same? How can we build environments to promote participation in home, schools, and communities? Can we increase frequency per week of a particular activity by partnering with community centers, specialized and non-specialized fitness centers, or local physical therapy education programs? Is it realistic to think that service delivery models, policy, and payment sources will support therapists as we move from center-based practices to practices in homes, schools, and communities? Will practice patterns and professional

training shift, as pediatric physical therapists become coaches, trainers, and supervisors for paraprofessionals and families in the community?

Critical Thresholds

Given the characteristics of the child, family, and environment, what is that threshold when change occurs at the level of body structures and function and activity and participation? What combination of factors is the tipping point at which structure and function are changed? When will the infant be able to crawl independently; when the eyes and head coordinate, or when the infant is very motivated and engaged in obtaining an object? What combination of factors needs to be in place for a child/infant to advance in motor skills? How do these factors vary given individual differences in children, families, and locations? How do these factors vary given the different motor skills?

Optimizing Dosing Given Genotype

The identification of alleles associated with CP and more recently, clinically relevant copy number variation¹¹¹ detected in genetic profile of children with CP provide insight as to why two infants can respond differently to the same type of brain injury or intervention. Do children with certain genetic characteristics require pharmacological interventions, such as dopamine, or does the dose of the intervention need to be increased? Does the environment need to be changed, e.g., supporting positive family practices for behavior management and stimuli or cognitive behavior therapy for the individual with CP?

Closing the Knowledge Gap about Effective Interventions for Individuals with Severe Motor Involvement.

Limited information on effective interventions for children GMFCS IV–V exists; although published reports are available on service utilization, feasibility of intense interventions,¹¹² and participation interventions to improve health related quality of life.¹¹³ Patterns of service utilization for children with varying levels of severity are not clear. Palisano et al.¹¹⁴ report children with more severe involvement ages 2 to 6 years receive more therapy in clinic and school settings in the US and Canada. Conversely, Bailes et al.¹¹⁵ report children with higher levels GMFCS levels receive less therapy in a large outpatient medical center in the US. Data from the National Survey of Children with Special Health Care Needs reveals children with more functional limitations have more unmet needs for therapy and mobility aids.¹¹⁶ For children with more severe involvement, patterns of service utilization may vary by geographic locations or setting, and it is not clear how utilization patterns are associated with better outcomes in the short or long term.

Several active clinical trials (clinicaltrials.gov) are investigating effective ways to measure and improve postural control in children with disability, a significant issue for individuals with severe gross motor impairment. Later in life, individuals with severe motor impairment are more likely to incur the greatest cost for care, as they are at highest risk for dependent care and development of costly secondary conditions.¹¹⁷ Participation interventions dosed appropriately, hold promise for improving body structures and function, and can promote health across the lifespan for individuals with severe motor involvement.

Adult Outcomes

There is a lack of information about interventions to promote participation of adults with CP. This gap in information is even more poignant when we consider that adults with CP outnumber children with CP. The needs of children with CP as they transition to young, middle, and later adulthood are largely unmet. We need to establish links between childhood treatments and positive adult outcomes in order to investigate if effort for some interventions have impact in the long term.¹⁰ How can we harness the potential for change of the cardiovascular, musculoskeletal, and central nervous systems to optimize health, wellness, and function? What are the needs and the differential preventative measures needed for people with different movement disorder sub types of CP?¹¹⁸ How can we best address the physical therapy needs of adults with CP?

Health Services Research

Population patterns in utilization of services, health status, participation, activity, consumer satisfaction and cost for rehabilitation services for people with chronic childhood conditions are largely unknown. Disease specific registries can be useful to monitor prevalence as well as long-term outcomes, and cost benefit ratio. Intervention specific information including discipline type, type of intervention, time, and frequency per week, is needed as routine data entry information in electronic health records for hospitals, school systems, and other practice settings. Developing an infrastructure for quality improvement is needed to analyze practice patterns.

IMPLICATIONS FOR PRACTICE

Three challenges are provided as an impetus for aligning practice with evidence. Significant social and financial barriers exist to meet these challenges, but reflection on these challenges is warranted.

Are we intervening too late or not at all? We have multiple tools to identify infants at risk. There is much that can be done before the child is diagnosed. Many critical periods are immediately after birth and during the first year of life. How can physical therapists provide information and services more consistently to families and infants at risk? Are we taking advantage of muscle and bone plasticity in middle childhood and throughout adolescence with adequately dosed interventions?

Are we doing enough? Intensity can refer to engagement, effort, or force production depending on intervention type. Are interventions dosed appropriately (thousands of repetitions for motor learning, 70% of 1 repetition max for strengthening) for effectiveness given the information we currently have? Is current evidence being used to prescribe exercise to promote changes for muscle, bone, and brain?

Measurement

Are we measuring what we are doing so we can evaluate best practice? Measurement is needed within sessions, across sessions, within hospitals-outpatient/outpatient, school, birth to three. Are we documenting the salient features of the intervention session? Are we

documenting important characteristics of the child, such as level of severity, cognition, communication, and family characteristics such as values and coping? How are we using the data we collect to improve practice?

CONCLUSION

Although parameters for dosing participation are not yet established, emerging evidence suggests participation at high enough intensities may yield changes. Given plasticity present immediately after birth and in the first year of life, intense participation interventions seem ideal for infants. Participation interventions if dosed appropriately may provide an additional avenue to promote change throughout the life span. Technology, social change, and change to the physical environment hold promise to provide participation interventions at high frequencies and intensities to promote change. To break the cycle of accumulated disability in individuals with CP, we need to continue to work on many fronts: bench science, clinical science, knowledge translation, advocacy, and institutional practices.

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Figure 1.

Path model for dosing interventions for children with cerebral palsy. Emphasis on the type, dose, age, plasticity of muscle, bone, and brain, and performance in everyday life. (reprinted with permission Gannotti ME, Christy JB, Heathcock JC, Kolobe TH. A path model for evaluating dosing parameters for children with cerebral palsy. *Physical Therapy*. Mar 2014;94(3):411–421.)

Figure 2.

Path model abbreviated for harnessing plasticity driven interventions and age at time of intervention

Figure 3.
Path model abbreviated for participation driven interventions and age at time of interventions

Table 1

Features of Intervention Types

	Type	Characteristics	Other Factors	Site Specific
Harnessing Plasticity	Resistance Training for Muscle Strength	High Resistance	Muscle length, type of contraction	Yes
	Velocity Training for Muscle Performance	High Resistance at High Speed	Muscle length, type of contraction	Yes
	Bone Loading for Bone Health	High impact (relative to usual)	Adequate nutrition, effects of medications	Yes
Harnessing Plasticity and Participation Driven	Activity Based Interventions to Improve Motor Skills and Body Structures & Function	Functional context, many repetitions, Active engagement Time spent performing	Feedback, task variation Opportunities for practice	Usually
Participation Driven	Contextual Interventions to improve activity & participation	Natural environment, active engagement	Individualized to preferences and context	Not determined

Table 2

Summary of Known Dosing Parameters and Optimal Timing

Type	Load	Repetitions	Speed	Frequency	Rest	Duration	Timing
Strength Resistance Training ¹	85% of 1RM	Build to 3 sets of 6–10	Slow to moderate; controlled	2–3 x/wk (non-consecutive)	1–2 min between sets; 24 hrs btw sessions	8–20 weeks	Age 5 years of age and above ²
Velocity Training ¹	40–80% of 1RM	Build to 6 sets of 5–6	Concentric part “as fast as possible” Return, slow and controlled	2–3 x/wk (non-consecutive)	1–2 min between sets; 24 hrs btw sessions	8–20 weeks	Age 5 years of age and above ²
Bone Mass and Structure ³	High ground reaction force	50–100	High strain	3–6 x/wk (non-consecutive)	1–10 sec btw reps; 4–8+ hrs btw sessions	9–12 months (min 3 months)	Pre-puberty; presence of growth hormones ³
Motor learning for Reaching Training ⁴	Mental engagement beneficial: Time 20 min, 2 hours, total time more than 90 hours	Dozens to hundreds	Task dependent	Task dependent, more than competing movement pattern?	Needed for consolidation	Months	First year of life; ⁵ again first 6–8 years of life ⁴

¹Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*. Aug 2009;23(5 Suppl):S60–79.

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