Treadmill protocols across ages and stages: A fresh look at dosage

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**Objectives**

1. Describe the theoretical and neuroplastic mechanisms behind infant treadmill protocols
2. Describe the available evidence on treadmill training in pre-ambulatory children with CP and neuromotor impairment
3. Describe muscle performance impairments in children with CP and the implications for treadmill training
4. Describe implementation and outcomes of short-burst interval treadmill training in ambulatory children with CP

**Infant Stepping**

- Infants are born with a stepping response
  - Legs are alternating
  - One leg has knee and hip extension
  - Other leg has knee and hip flexion
- Usually “disappears” in the first 2 months of life

**Manipulating the Stepping Response**

- Thelen showed that the stepping response can be manipulated (1982)
  - In infants who still exhibit the stepping response, adding weight to their legs will make it disappear
  - In infants who no longer exhibit the stepping response, submerging their legs in water will make it reappear
- Zelazo showed that if the stepping response is practiced is does not disappear AND children who practice stepping walk earlier (1972, 1983)
Infant Stepping in Supine?

- Video of 5-month old baby with typical development
- The stepping movement does not really disappear but takes the form of supine kicking. (Thelen and Fisher, 1982)
  - Has less strength demands that upright stepping
- Typically Developing infants are practicing the stepping pattern well before they start to pull to stand

How does this relate to the Treadmill?

- Children who are not typically developing do not develop supine kicking in the same way
  - So, they do not get the same amount of stepping practice
  - Children with DS show less antigravity movement (Ulrich and Ulrich, 1995)
  - Infants born preterm display decreased dissociation of their lower limbs when kicking (Jeng, Chen, & You, 2002)
  - One way to help children with DD practice a stepping pattern is the treadmill

Practice leads to synaptic change

- A synapse changes in strength depending on its past activity
  - Increased frequency of firing or strength of activation leads to Long-Term Potentiation (more likely to fire again)
  - Decreased frequency of firing or strength of activation leads to Long-Term Depression (less likely to fire again)
- Long-term potentiation is enhanced in the young brain (Crair and Malenka, 1995)
  - Children have more synapses than adults (Huttenlocher & de Court, 1987)
  - This provides more neurological options and greater plasticity

How does the treadmill help?

- It provides an environment that helps to facilitate stepping
- It provides the opportunity for multiple repetitions
- It provides the opportunity for variable practice
- It allows for a varied level of trunk control

Variable Repetition

- Gait is an individual solution to the problem of how to get from point A to point B
  - So development of the pattern is individualized too
- Variable repetition allows for an adaptive pattern

Down Syndrome: An example of treadmill training in action

- 8 min./day, 5 days/week
- Support infant’s body weight through the trunk
- Allow the infant to actively explore the stepping pattern
- Infants seem to respond to the treadmill when they begin to sit independently

Looper, Mattern-Baxter, Moreau, Bjornson, AACPDM 2017
Down Syndrome: An example of treadmill training in action

• Leads to earlier walking onset (101 days on average) (Ulrich et al, 2001)
• Better gait parameters (Wu et al., 2007)
• Increased intensity led to improved gait parameters and ability to clear an object (Wu et al., 2007)
• Waiting until the children can pull to stand may be too late (Looper & Ulrich, 2010)

References

• Looper J, Ulrich DA. Effects of various treadmill interventions on the development of joint kinematics in infants with Down syndrome. Phys Ther. 2010; 90(9):1265-76.

Objective

2. Describe the available evidence on treadmill training in pre-ambulatory children with CP and neuromotor impairment
Participants

- 175 children (101 in treadmill training, 74 controls)
  - 41 infants at moderate risk for developmental delay
  - 20 cerebral palsy
  - 24 general developmental delay
  - 90 Down syndrome

Organized by ICF Model

- Body Function & Structure
  - Step frequency
  - Step quality (toe versus flat foot contact)
  - Walking speed and other gait parameters (step width, etc)
- Activity & Participation
  - Age of independent walking onset
  - Age of walking onset with assistance
  - Gross motor function
  - Adverse events
  - Quality of life

Meta-analysis: Effect of treadmill on
age of onset of walking with assistance

- Population dependent

Meta-analysis: Effect of treadmill on
gross motor function

- No benefit for total GMFM % scores
- Some benefits in individual studies on GMFM Dim D and E in CP and DD

Meta-analysis: Effect of treadmill on
independent walking onset

- Population-dependent
  - Children with DS benefited
  - Infants with moderate risk for developmental delay did not

Summary of Main Results- BS&F

- Children w/CP
  - No effect on step frequency, velocity, step length or double limb support
- Infants w/ mod. risk for DD
  - + effect on step quality
  - No effect on on step frequency, velocity or other gait parameters
- Children w/ DD who were ambulatory
  - + effect on gait velocity
- Children w/DS
  - + effect on alternating steps after high intensity training
  - None on step length, step width or toe-off
Summary of Main Results-Activity

- Children w/CP
  - + on GMFM E scores (small effect)
  - No effect on overall GMFM scores
  - + effect on Peabody Developmental Motor Scale-2 scores
- Infants w/ mod. risk for DD
  - No effect on independent walking onset or walking with assistance
- Children w/ DD who were ambulatory
  - + effect on GMFM D and E scores

Subjects

- Inclusion criteria
  - Cerebral palsy
  - GMFCS levels I-II
  - Ages 9 to 36 months
  - Signs of walking readiness
    - Sits for 30 sec
    - Takes 5-7 steps when supported by adult
- Exclusion criteria
  - Genetic syndrome
  - Medical contraindication for standing or walking
  - Spasticity reducing medication in the past 6 months
  - Previous or current use of treadmill in PT

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Study Design

- 6 weeks, home-based
- 6x/week, twice daily, for up to 20 min/each
- Minimal manual contact
- Progressively increased speed
- Mean minutes walked/day: 28.2 ± 11.2
Outcome Measures

- Blinded
  - Gross Motor Function Measure-66 (GMFM-66) Dimension D and E
  - Peabody Developmental Motor Scales-2 (PDMS-2) Locomotion Subscale
- Parent-Reported
  - Pediatric Evaluation of Disability Inventory (PEDI)
  - Mobility Scale
- Fast Timed 10-meter walk test
- Functional Mobility Scale

Results

Functional Ambulation

Perceived Problem

Walking Speed

Translation of Clinical Research into Practice

Supported Treadmill Exercise Program at Sacramento State-Easter Seals = STEPS
Funding

- University Enterprises, Inc. Campus Program Grant, CSU, Sacramento
- Pillars of Giving, Easter Seals Superior, CA
- Center for Excellence in Developmental Disabilities, UC Davis MIND Institute
- Donations from individuals

Subjects

- n=12
  - n=4 Cerebral Palsy
  - n=5 genetic syndrome
  - n=3 other
  - Mean age 30.4 (19-47) months
  - M:F ratio 7:5

STEPS-Overview

- Free group-based treadmill program at University
- Twice weekly sessions during spring and fall semesters for 14 weeks
- Sessions individualized for each child
- 3-5 DPT students/day, supervised by PT/faculty
- Additional over-ground walking activities
- Consultation/collaboration on orthotics/equipment
- >50 children served since Spring 2013

Program Admission

Child receives physical therapy

- Child shows signs of walking-readiness
  - sit for 30 seconds
  - take 5-7 steps when supported
- Does not have any exclusion criteria
  - Uncontrolled seizures
  - Prior orthopedic surgery/contraindications for standing/walking

PT refers child to STEPS

Child attends treadmill sessions in addition to ongoing PT until independent walking onset or age 5 years

Outcome Measures

- At program entry and at end-of program
  - Timed 10 meter walk test
  - Gross Motor Function Measure, Dimensions D and E
  - Pediatric Evaluation of Disability Inventory- Mobility Caregiver Scale
  - Functional Mobility Scale
Results

Mean Minutes Walked/Week

Mean Treadmill Speed

Program Utilization

77%

23%

Parent Survey

Results

GWFM Dimension D

GWFM Dimension E

PEDS-Cerebral Mobility Scale

Parent Comments

• “The atmosphere is so positive and encouraging—we don’t get that in a clinical PT setting.”

• “The STEPS program has been amazing! My daughter has gained so much motor development that I know she would not have had this time if she wasn’t in the program.”

• “The STEPS program was amazing! My daughter is doing so much more than she was prior to being in the program.”

• “Staff was awesome. Glad I could bring my other child. Love the staff. They were patient and encouraging and fun.”

• “Excellent all around. We are so sad to say goodbye. I wish there were a similar program in (the county the family was moving to).”

Conclusions

• Group-based treadmill programs can
  – ↑ Developmental skill related to standing/walking
  – ↓ Support needed for walking
  – ↓ Caregiver dependence for mobility
  – Provide good utilization/ high satisfaction by families
  – Provide cost-effective alternative as an adjunct to PT
Current Research

- Funded study to examine optimal dosage
  - Intensive home-based treadmill training and walking attainment in young children with cerebral palsy
    (Mattern-Baxter, Bjornson, Looper)
  - Enrolling 24 children with spastic CP
    • Currently 15 children enrolled
  - High-intensity versus low-intensity treadmill training
  - Effects on walking attainment and physical activity

References


Objective

3. Describe muscle performance impairments in children with CP and the implications for treadmill training

Theoretical Framework for Improving Walking

- Task-Specific
  (Treadmill, BWSTT, robotic devices)
  Do we need more practice?
- Impairment-based
  (strength, power, ROM)
  Are we lacking the underlying muscular resources?
**Theoretical Framework**

International Classification of Function (ICF)

- Cerebral Palsy
- Muscle Architecture
- Muscle Function
- Gross Motor Function
- Action
- Participation
- Body Structure
- Body Functions
- Muscle Function
- Action
- Participation
- Society
- Treatment & Dosing

**Muscle Architecture**

- Force Production
- Shortening Velocity

**Muscle Plasticity**

Specificity of Training

**Muscle Architecture**

- Muscle architecture determines the force-velocity properties of muscles!!

**Muscle Structure – Function Relationships in CP**

Muscle Performance
- Strength
- Power

**Architectural Basis for Strength Deficits in CP**

- Decreased muscle volume and cross-sectional area of LE (14% to 50%) (Lampe et al., J Menstr Gynecol, 2006; Oberhoffer et al., Clin Biomech, 2010; Moreau et al., JMC, 2005; Elder et al., JMC, 2010; Malaiya et al., Electromyogr Kinesiol, 2007)

- Less sarcomeres working in parallel results in a decrease in force-generating capacity

- Overlengthened sarcomeres
  - Säber & Földesi, Muscle Nerve, 2002; Smith et al., J Phys, 2011)
**Strength Training??**

- Increase in plantarflexor muscle volume after 8 weeks of strength training (McNee et al, JMCV, 2009)
- Increase in quadriceps cross-sectional area and muscle thickness after 8 weeks of knee extensor strength training (Moreau et al, NNR, 2013)

**Muscle Power**

- "the ability to exert a maximal force in as short a time as possible"
- "generating as much force as fast as possible"

**FORCE X VELOCITY**

**Muscle Plasticity - Strength**

*Evidence for muscle hypertrophy in response to strength training in CP!*

- Increase in plantarflexor muscle volume after 8 weeks of strength training (McNee et al, JMCV, 2009)
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**Architectural Basis for Muscle Power Deficits**

- Force Production
- Shortening velocity

**Muscle Power - CP**

- 64% of TD children
- 82% ↓ by
- 18%

**Strength Training**

- Effect size: 0.06 (CI = 0.15, 0.27) (p = .59) (standardized)

There is no higher level evidence that resistance training improves walking speed or other measures of functional walking capacity (Scianni et al, JPT, 2009; Verschuren et al, PJE, 2011; Moreau et al, PJE, 2010)
Power Training??

Treadmill Training??

Muscle Plasticity - Power

*Muscle architectural changes specific to power/velocity training in CP and improved walking!*

- Increase in rectus femoris cross-sectional area and fascicle length after 8 weeks of velocity training for knee extensor muscle power! (Moreau et al, NNR, 2013)
- Accompanied by increases in walking speed and functional mobility!!

Evidence - Summary

- *Muscle power may be a key ingredient for walking capacity/performance and other functional activities, such as transfers!*
- Improvements in strength alone do not translate into improvements in walking
Can Treadmill Training Provide an Adequate Stimulus to Effect Changes in Muscle Architecture and Power?

- BWSTT, traditional overground, or Robotic -> NO!
- Children with CP have difficulty ramping up their walking intensity to moderate and high levels.
- Ho: Requires muscle power as an underlying resource, and muscle power generation is significantly impaired in CP!!

Activity Patterns Differ Between Children and Adults!

Can Treadmill Training Provide an Adequate Stimulus to Effect Changes in Muscle Architecture and Power?

- Current Work: Does treadmill training delivered in intervals of high intensity walking alternating with low/moderate intensity provide the necessary stimulus?
- Up Next!! Results from R21 Pilot study...

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REFERENCES:

- PMCID: PNC0004055.
Objective

4. Describe implementation and outcomes of short-burst interval treadmill training in ambulatory children with CP

Short-burst Interval Locomotor Training

- will enhance muscle power production and subsequently
- walking performance and capacity
- through training patterns that are motivating
- and mirror the walking and physical activity patterns of TD youth

Background/significance:

- Muscle power production and rapid force development are deficient in children with CP as compared to TD youth (Moreau, 2013 & 2012).
- Youth with CP have limitations in the ability to ramp up their walking activity into medium and/or high stride rates. (Bjornson, 2013, 2007)
- TD children engage in very short bursts of intense walking and physical activity interspersed with varying intervals of low and moderate intensity (Armstrong, 1990; Bayley, 1995).
- LTT protocols for children with CP have been based on adult walking activity patterns and do not approximate the high intensity short burst patterns of TD children (Dobkin, 2006; Duncan, 2011)

Outcomes:

- Walking Capacity – clinic based measures
  - 10 meter walk test (10MWT) - m/sec
  - Self-selected walking speed
  - Fast walking speed
  - 1 Minute Walk Test (1MWT) – meters
  - Timed Up and Go (TUG)
Outcomes:
- Walking Performance - community walking activity
  - StepWatch accelerometer
  - Average Strides/day
  - Peak Activity Index - average step rate/minute of the highest 30 minutes/day
  - % of walking time:
    - low, moderate and high activity*


Outcomes:
Physical Activity, Participation, Fatigue, Mobility, Pain
- Activity Scale for Kids (ASKp-30)
- Assessment of Life Habits –LIFE-H
  - Housing
  - Mobility
  - Recreation
- Patient Reported Outcome Measure Information System (PROMIS)
  - Fatigue
  - Mobility
  - Pain interference
  - Pain intensity

Study Sample:
- N = 12, Spastic Diplegia
- GMFCS Levels: II = 8; III = 4
- Average Age: 8.6 (5.9 to 11.9)
- Female= 5; Caucasian – 5, Hispanic -1
- Mother had some college education -6
- Owned their homes -7
- Solid Ankle AFO/AFOFC-6
- Independent walking primary mode of mobility
- Exclusion:
  - ortho/neurosurgery in last 12 months
  - injection therapy in last 3 months
  - serial casting in 30 days
  - Uncontrolled seizure disorder

Methods:
- Ambulatory activity were derived from the average of 5 days of StepWatch accelerometry data.
- Walking stride activity was defined as
  - Low 1-30 strides/min
  - Moderate 30-60 strides/min
  - High > 60 strides/min


Short Burst Interval Training Protocol:
- 20 total sessions
- Randomized to either
  - 5 days/week over 4 weeks
  - 2 days/week over 10 weeks
- 30 minutes total treadmill walking
  - 30 seconds - self selected speed – “slow”
  - 30 seconds - fast walking speed - “fast”
- Wearing current clinically prescribed orthotics
- Training speeds based on 75% of baseline 10 meter walk tests

Short Burst Interval Treadmill training:
Training Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Average slow speed/session -mph</td>
<td>1.4</td>
<td>[0.5 – 2.6]</td>
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<tr>
<td>Average fast speed/session -mph</td>
<td>2.5</td>
<td>[0.6 -3.4]</td>
</tr>
<tr>
<td>Average total time trained/session-mins</td>
<td>28.8</td>
<td>[15.1 - 31.1]</td>
</tr>
<tr>
<td>Average Peak Omni score/session</td>
<td>3.9</td>
<td>[0.73 -8.8]</td>
</tr>
<tr>
<td>Average # of rests/session</td>
<td>0.6</td>
<td>[0 - 4.1]</td>
</tr>
<tr>
<td>Parent Satisfaction with training 1-10 scale; 10= complete satisfaction</td>
<td>9.42</td>
<td>[7-10]</td>
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</table>
Results: Walking Capacity – clinic measures

Results: Community Walking Performance

<table>
<thead>
<tr>
<th>Walking Capacity *normalised outcome (n=12, PRE/POST SBLTT)</th>
<th>BL Mean (SD)</th>
<th>Post 1 Mean change</th>
<th>Post 2 Mean change</th>
<th>p value</th>
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<tbody>
<tr>
<td>One minute Walk Test (meters)</td>
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<td>10 Meter Walk Test Self selected speed (m/s)</td>
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<td>10 Meter Walk Test Fast speed (m/s)</td>
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<td>Timed Up &amp; Go (secs)</td>
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<thead>
<tr>
<th>Average Strides/day at baseline, post SBLTT and 6 weeks post SBLTT (n=12)</th>
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<tr>
<th>Walking Performance (n=12, PRE/POST SBLTT)</th>
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<tbody>
<tr>
<td>BL Mean (SD)</td>
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<tr>
<td>-------------------------------------------------------------</td>
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<tr>
<td>Average Total Steps/day</td>
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<tr>
<td>Percent Time walking</td>
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<tr>
<td>Percent Time &gt; 30 steps/min (Mod/High)</td>
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<td># Step &lt;30 steps/min</td>
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<td>Peak Activity Index (ave top 30 one min)</td>
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<td>Max # steps 60 mins</td>
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<td>Max # steps 20 mins</td>
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Preliminary results R21 (n=12) SBLTT for R01: StepWatch community walking intensity improved

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<thead>
<tr>
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<th>BL Mean (SD)</th>
<th>Post 1 Mean change</th>
<th>p value</th>
<th>BL to Post 2 Mean change</th>
<th>p value</th>
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<tr>
<td>Activity Scale for Kids (ASKp-30) summary score</td>
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<tr>
<td>Life-H: Housing weighted score</td>
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<td>Life-H: Mobility weighted score</td>
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<td>Life-H: Recreation weighted score</td>
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<td>PROMIS: Fatigue T-score</td>
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<td>PROMIS: Mobility T-score</td>
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<td>PROMIS: Pain interference T-score</td>
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<td>Pain Intensity</td>
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Results: Daily Physical Activity, Participation, Fatigue/Pain

Results: Dosing Frequency - Preliminary comparison
N=6/intervention frequency

- Comparison of the high frequency (5x/week) versus low frequency (2x/week) SBLTT:
  - No difference across all walking capacity and performance outcomes (n=6/intervention frequency, p = .24 -.70).
  - EXCEPT
    - Self-selected walking speed was greater for the high frequency group at 1 week post training (+0.21 m/sec, p = .03)

Parental report of Activity Scale for Kids-Performance at baseline, post SBLTT and 6 weeks post SBLTT (n=12).

Thinking about the training sessions that you and your child just finished doing, how did you feel about the training overall?

- Liked it a lot; wish we could keep doing it
- Very positive. [Child] worked hard and I could see his stride lengthening.
- Very happy with him being able to walk farther/not use wheelchair for ~2 mile walks
- It was time consuming but nice to get a lot of therapy in over the summer, especially without having to drive somewhere for it.
- Training itself while tiring was very good.
- Very good
Thinking about the training sessions that you and your child just finished doing, how did you feel about the training overall?

Continued....

- Overall, training program is a very good one.
- Treadmill training easier than expected. Good study design.
- Good practice, enjoyed participation, enjoyed research PT
- Good! Not too hard for [my child], easy to work out schedules with PT.
- Very satisfied. Child had fun and got stronger. The timing was great and convenient for all of the sessions.
- Wonderful! My son loved it, and we can see already how it has helped him. It was easy for us to manage at home and all professionals involved were awesome!

“TAKE HOME PEARLS & NEXT STEPS G”

- R21 data suggests: SBLTT training appears to have some positive influence
  - Walking capacity (clinic)
  - Community walking activity
  - Parent report of physical activity
  - Effect on participation/Fatigue/pain
- Low vs High frequency SBLTT (?)
- Randomized clinical trial (RCT) examining dosing, muscle outcomes and community walking

REFERENCES: