Enhancing muscle health and function in cerebral palsy: What we need to know.

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**Speakers Name:** Prof Susan Stott, Dr Sîan Williams, Shari O’Brien

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**Disclosure of Off-Label and/or investigative uses:**
I will discuss the following off label use and/or investigational use in my presentation: Onabotulinum Neurotoxin Type-A
Learning objectives

1. To understand early musculoskeletal development in CP.
2. To understand muscle adaptations in CP across the lifespan.
3. To understand interventions in CP across the lifespan.
4. To understand early interventions to maintain musculoskeletal and cardiovascular health and reduce sedentary behaviour in children with CP.
Early musculoskeletal development in CP
CP Muscle

- Gross muscle morphology and structure in spastic cerebral palsy: a systematic review
  - ROD S BARRETT | GLEN A LICHTWARK

- Muscle growth is reduced in 15-month-old children with cerebral palsy
  - ANNA HERSKIND | ANINA RITTERBAND-ROSENBAUM | MARIA WILLERSLEV-OLSEN | JAKOB LORENTZEN | LARS HANSON | GLEN LICHTWARK | JENS B NIELSEN

- Subject-specific modelling of lower limb muscles in children with cerebral palsy
  - K. Oberhofer, N.S. Stott, K. Mithraratne, I.A. Anderson

- The morphology of the medial gastrocnemius in typically developing children and children with spastic hemiplegic cerebral palsy
  - Rita Malaya, Anne E. McNee, Nicola R. Fry, Linda C. Eve, Martin Gough, Adam P. Shortland

- MRT-measurements of muscle volumes of the lower extremities of youths with spastic hemiplegia caused by cerebral palsy
  - Renée Lampä, Stefan Grassl, Jürgen Mitternacht, Ludger Gerdsemeyer, Reiner Gradnner
Linked with ... Muscle Strength
Hemiplegia with Equinus contracture (Untreated)
### Variables of Muscle

<table>
<thead>
<tr>
<th>Muscle belly length</th>
<th>Muscle thickness</th>
<th>Anatomical Cross Sectional Area</th>
<th>Muscle Volume</th>
<th>Physiological Cross Sectional Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Muscle belly length" /></td>
<td><img src="image2.png" alt="Muscle thickness" /></td>
<td><img src="image3.png" alt="Anatomical Cross Sectional Area" /></td>
<td><img src="image4.png" alt="Muscle Volume" /></td>
<td><img src="image5.png" alt="Physiological Cross Sectional Area" /></td>
</tr>
</tbody>
</table>

- Fascicle length, Pennation angle

\[
\text{PCSA} = \frac{\text{Muscle volume} \times \cos \theta}{\text{Fascicle length}}
\]
CP v TD muscle volume (Medial Gastrocnemius)

Study and Age (years)
Heterogeneity

n= 10 CP
GMFCS I-III
Aged 11-17 years
Muscle Volume (normalised to height * mass)

Handsfield et al., 2016
Heterogeneity

Handsfield et al., 2016
Heterogeneity

- HS release
- G-S lengthening
- G-S lengthening + Fem. derotation
- G-S lengthening
- G-S lengthening
- G-S lengthening

Handsfield et al., 2016
Heterogeneity

HS lengthening, dorsal rhizotomy

Typically Developed

Anterolateral Posterior

smaller than typical

larger than typical

Handsfield et al., 2016
Heterogeneity

Muscle Volume
- ~20% lower in CP
- Varied between
  - Muscles 12%-43%
  - Individuals
  - Distal involvement

Handsfield et al., 2016
## Heterogeneity: GMFCS

<table>
<thead>
<tr>
<th>Study</th>
<th>Muscle Volume Deficit/Volume</th>
<th>Age</th>
<th>GMFCS I</th>
<th>GMFCS II</th>
<th>GMFCS III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitcher et al., 2018</td>
<td>Triceps surae muscle volume deficit</td>
<td>5-12 years</td>
<td>- 13.6%*</td>
<td>-34.7%*</td>
<td></td>
</tr>
<tr>
<td>Handsfield et al., 2016</td>
<td>Lower limb muscle volume</td>
<td>11-17 years</td>
<td>≤ 95% CI</td>
<td>≥ 95% CI</td>
<td></td>
</tr>
<tr>
<td>Herskind et al., 2015</td>
<td>MG Muscle volumes</td>
<td>8-65 months</td>
<td>-7.9 ml</td>
<td>-12.84 ml</td>
<td>-19.1 ml</td>
</tr>
</tbody>
</table>

Inverse relationship with GMFCS level?
### Heterogeneity: Between legs

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (years)</th>
<th>TD</th>
<th>Hemiplegic</th>
<th>Less Involved</th>
<th>Involved Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaiya et al., 2007</td>
<td>4-12</td>
<td>81.1 cm³</td>
<td>66.4 cm³</td>
<td>48.1 cm³</td>
<td></td>
</tr>
<tr>
<td>MG Muscle volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obts et al., 2017</td>
<td>m=6.0 (SD 2.4)</td>
<td>46.8 cm³</td>
<td>41.3 cm³</td>
<td>30.2 cm³</td>
<td></td>
</tr>
<tr>
<td>MG Muscle volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen et al., 2018</td>
<td>2-13</td>
<td>45.1 mm</td>
<td>40.7 mm</td>
<td>36.6 mm</td>
<td></td>
</tr>
<tr>
<td>Sol Fascicle length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Estimates of muscle growth in CP

<table>
<thead>
<tr>
<th>Age (years)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barber et al., 2013</td>
<td>2-5</td>
<td>0.90</td>
</tr>
<tr>
<td>Willerslev-olsen et al., 2018</td>
<td>0-4</td>
<td>0.52</td>
</tr>
<tr>
<td>Fry et al., 2007</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td>Herskind., 2007</td>
<td>1-5</td>
<td>0.68&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>McNee et al., 2009</td>
<td>6-16</td>
<td></td>
</tr>
<tr>
<td>Williams et al., 2013</td>
<td>5-12</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Growth rate estimates from manuscript data

<sup>b</sup> Bilateral CP

<sup>c</sup> Plantar flexor group
MG Growth Rate

Data are median (MAD). * Significant within group difference from baseline to 12 months follow-up (p<0.01). $\Psi$ Significant between group difference compared to TD (p<0.01).

Barber et al., 2013
Hemiplegic vs Diplegic CP

Estimated Growth rate
ml/month

TD = 0.73
DCP = 0.48
HCP = 0.17*

Barber et al., 2016
MG growth: HCP < DCP

<table>
<thead>
<tr>
<th>BoNT-A</th>
<th>HCP ≈ DCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFCS I</td>
<td>HCP(64%) &gt; DCP(42%)</td>
</tr>
<tr>
<td>Limb loading and activation</td>
<td>HCP &lt; DCP</td>
</tr>
</tbody>
</table>

Learned behavioural suppression of lower limb loading of the more impaired limb

Barber et al., 2016
MG ‘Growth’ Rate

- TD (n=100)
- CP, GMFCS I-II (n=26)

Slope
- TD $r^2 = 0.87$
- CP $r^2 = 0.37^*$

Herskind et al., 2015
MG ‘Growth’ Rate

Growth rate (ml/month)
TD = 0.52  \( r^2 = 0.67 \)
CP = 0.34  \( r^2 = 0.74 \)

Willerslev-Olsen et al., 2018
Muscle growth... use it or lose it?

- Motor milestones
- Mechanical loading
- Physical activity

↓ Hypertrophy?
Quadriplegic CP
• 2.3 x intermuscular AT
• 51% lower muscle CSA

Physical activity

Johnsen et al., 2009
Muscle quality: Intra-muscular fat

Figure 2: Percentage IntraMF and IMAT in the medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SOL), tibialis anterior (TA), tibialis posterior (TP) and in the BSCP group (white) and TD group (grey). IMAT and IntraMF in all muscles were significantly different between groups (p < 0.05). Error bars represent the standard error of each group.

Noble et al., 2014

Young adults with CP
- ↑ intra-muscular fat
- ↑ inter-muscular AT
Quantitative ultrasound in CP

n=40 children with CP, GMFCS I-V

• Echo Intensity:
  • CP > TD
  • Correlated to GMFCS

Pitcher et al., 2015
Muscle quality: Echo Intensity

TD (n=10)  Hemi CP (n=26)

Typically Developed  CP (less involved)  CP (more involved)

CSA=65.7 cm²  CSA=45.1 cm²  CSA=32.0 cm²
CSA=65.8 cm²  CSA=45.1 cm²  CSA=38.3 cm²
CSA=34.8 cm²  CSA=16.8 cm²  CSA=17.5 cm²
Muscle Histology

- ↑ Lipid content
- ↑ Collagen content (correlated with stiffness)
- ↓ Satellite cells
- ↓ Fibre size (↑ variability)
- ↑ Type 1 / change in %

% Fibre type = reflects use

Mathewson & Leiber, 2016
Muscle changes with age

Natural history still a mystery

Secondary Sarcopenia

– Decreased Activity Levels
– Muscle quality
– Nutrition

Verschuren et al., 2018
Trajectory of muscle adaptations and interventions to improve muscle impairments and function in individuals with CP.
Exercise to improve muscle health

Established benefits of muscle mass in TD individuals:

↓ Cardiometabolic risk factors

↑ Bone mineral density and strength

↑ Muscular strength, endurance and power
Impact of reduced muscle mass

Bulk of metabolic tissue
- Resting metabolism
- Energy balance
- Insulin resistance
- Diabetes
- Obesity

Bone loading
- Osteoporosis

Wolfe., 2006
Strength reserve

Muscle strength/bw

Age

E

F

D

Functional threshold

Shortland, 2009
Types of training studies in CP

- Anaerobic
- Gait
- Resistance
- Combined
- Functional
Strength training in CP

- 4 days/week, 10 weeks
  - 3 sessions performed at home
- Exercise program:
  - Aerobic warm up
  - PF stretches
  - PF strengthening
    - Unilateral calf raise or theraband
    - 3-4 sets
    - 6-12 reps
    - 2 mins rest
  - Cool down + stretches

MG 17% ↑
LG 14% ↑

McNee et al., 2009
High intensity resistance training

**Exercises:** Ankle plantar flexion (seated, leg press); ankle dorsiflexion; leg press; hamstring curl; seated abdominal crunch; back extension.

**Table 2.** Strength training descriptors of the exercises performed in the intervention group.

<table>
<thead>
<tr>
<th>Load</th>
<th>Unilateral, 12RM (wk 1–4), 10RM (wk 5–6), 8RM (wk 7–8), and 6RM (wk 9–12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitions</td>
<td>12 (wk 1–4), 10 (wk 5–6), 8 (wk 7–8), and 6 (wk 9–12)</td>
</tr>
<tr>
<td>Sets per session</td>
<td>3 sets</td>
</tr>
<tr>
<td>Rest between sets</td>
<td>90 s</td>
</tr>
<tr>
<td>Sessions per week</td>
<td>3 per wk</td>
</tr>
<tr>
<td>Duration of training period</td>
<td>12 wk</td>
</tr>
<tr>
<td>Contraction modes</td>
<td>3 s concentric, 3 s eccentric (wk 1–2)</td>
</tr>
<tr>
<td></td>
<td>1 s concentric, 3 s eccentric (wk 3–12)</td>
</tr>
<tr>
<td></td>
<td>0 s</td>
</tr>
<tr>
<td></td>
<td>Max 216 s/exercise/session</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Rest between repetitions</td>
<td></td>
</tr>
<tr>
<td>Time under tension</td>
<td>Maximum possible, 90° knee flexion in leg extension</td>
</tr>
<tr>
<td></td>
<td>≥48 h</td>
</tr>
<tr>
<td>Rest between training sessions</td>
<td>Yes</td>
</tr>
<tr>
<td>Anatomical definition of the exercises</td>
<td>Yes</td>
</tr>
</tbody>
</table>
High intensity resistance training

**1RM strength**

<table>
<thead>
<tr>
<th></th>
<th>Baseline (kg)</th>
<th>12 weeks (kg)</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexion</td>
<td>5.7±0.6</td>
<td>10.4±1.1*</td>
<td>83%</td>
</tr>
<tr>
<td>Plantar flexion</td>
<td>30.3±4.9</td>
<td>71.8±6.7*</td>
<td>137%</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>16.3±2.0</td>
<td>29.5±3.1*</td>
<td>82%</td>
</tr>
<tr>
<td>Knee extension</td>
<td>72.3±5.8</td>
<td>104.5±6.7*</td>
<td>45%</td>
</tr>
</tbody>
</table>

* p<0.001

**Dorsiflexor rate of force development (RFD)**

![Graph A](#)

![Graph B](#)

Kirk et al., 2016
Strength training in CP

- ↑ muscle size
- ↑ strength
- Confounding factors
- Lack of objective outcome measures
- Training mode/dosage heterogeneity

Neuromuscular adaptations to strength training in CP poorly understood

Gillett et al., 2016
Combined strength and anaerobic training

FAST CP:

- 3 days/week, 12 weeks
- Progressive resistance training + functional anaerobic training

Gillett et al., 2018

Functional Anaerobic and Strength Training in Young Adults with Cerebral Palsy

JARRED G. GILLET1, GLEN A. LICHTWARK2, ROSLYN N. BOYD1, and LEE A. BARBER1

1Queensland Cerebral Palsy and Rehabilitation Research Centre, UQ Child Health Research Centre, Faculty of Medicine, The University of Queensland, South Brisbane, Queensland, AUSTRALIA; and 2Centre for Sensorimotor Performance, Faculty of Health and Behavioural Sciences, School of Human Movement and Nutrition Sciences, The University of Queensland, St Lucia, Queensland, AUSTRALIA

Figure 2 Flow chart outlining the resistance exercise training circuit. Starting exercise station for each session may vary between training sessions. Exercise order will be preserved.
<table>
<thead>
<tr>
<th>Exercise</th>
<th>Equipment</th>
<th>Description</th>
<th>Targeted fitness component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step-ups</td>
<td>Step or block</td>
<td>Step up with right leg over the block followed by the left. Turn around and step back over the block with left leg first. Count the number of repetitions completed</td>
<td>Strength, power, coordination</td>
</tr>
<tr>
<td>Beanbag run</td>
<td>4 mats, 12 beanbags</td>
<td>Place 4 mats in a row, 1.5 m apart. Place 4 beanbags on each of the first 3 mats. Move a beanbag from mat 1 to 2, 2 to 3, and 3 to 4. Run back to the start and repeat. Count the number of beanbags moved</td>
<td>Power, agility, coordination (bending, turning, getting up from the floor)</td>
</tr>
<tr>
<td>Lateral step-ups</td>
<td>Step or block</td>
<td>Step up sideways with right leg first over the block. Step back over the block with left leg first. Count the number of repetitions completed</td>
<td>Strength, power (stair climbing, avoiding obstacles)</td>
</tr>
<tr>
<td>5 m sprint</td>
<td>2 strips of tape</td>
<td>Place tape 5 m apart. Sprint as fast as possible between lines of tape. Count the number of sprints completed</td>
<td>Agility, speed</td>
</tr>
<tr>
<td>Obstacle course</td>
<td>1 hoop, beanbags, step, hurdle, basket</td>
<td>Take a beanbag from the hoop, over the step, under the hurdle and into the basket. Repeat and count number of repetitions completed</td>
<td>Power, agility, speed, coordination (bending, turning, getting up from the floor)</td>
</tr>
<tr>
<td>Shuttle sprint</td>
<td>5 lines of tape placed 1.5 m apart</td>
<td>Sprint to line 1, return to start. Sprint to line 2, return to start, continue. Count the number of lines touched</td>
<td>Power, agility, speed, coordination</td>
</tr>
<tr>
<td>Up and down stairs</td>
<td>3 stairs (17.5 cm step height)</td>
<td>Move up and down 3 stairs as quickly as possible. Count number of repetitions completed</td>
<td>Strength, power (stair climbing)</td>
</tr>
<tr>
<td>Agility run</td>
<td>Bean bag, cones, basket</td>
<td>Zig-zag between 5 cones placed 1.5 m apart (in and out), and return to the start line. Count number of repetitions completed</td>
<td>Power, agility, speed, coordination</td>
</tr>
<tr>
<td>4 cone run</td>
<td>4 cones of different colours</td>
<td>Start in the centre of a 2 m x 2 m square. Trainer calls a colour to run to, touch the cone, and back to the centre. Trainer then calls another colour. Count the number of cones touched</td>
<td>Power, agility, speed, coordination</td>
</tr>
</tbody>
</table>

FAST, functional anaerobic and strength training.
<table>
<thead>
<tr>
<th>Outcomes</th>
<th>T1 (Baseline), Mean (SD)</th>
<th>T2 (12 wk) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muscle volume (mL)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More impaired limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG</td>
<td>115.50 (48.85)</td>
<td>145.12 (53.75)</td>
</tr>
<tr>
<td>LG</td>
<td>62.81 (19.07)</td>
<td>87.93 (29.49)</td>
</tr>
<tr>
<td>SOL</td>
<td>248.37 (151.73)</td>
<td>313.37 (76.99)</td>
</tr>
<tr>
<td>Total PF (summed MG, LG, SOL)</td>
<td>425.91 (205.76)</td>
<td>545.71 (150.33)</td>
</tr>
<tr>
<td>TA</td>
<td>56.20 (21.51)</td>
<td>70.43 (19.74)</td>
</tr>
<tr>
<td>Less impaired limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG</td>
<td>161.77 (79.91)</td>
<td>172.41 (98.39)</td>
</tr>
<tr>
<td>LG</td>
<td>80.56 (39.24)</td>
<td>92.04 (31.24)</td>
</tr>
<tr>
<td>SOL</td>
<td>286.25 (121.32)</td>
<td>342.84 (78.59)</td>
</tr>
<tr>
<td>Total PF (summed MG, LG, SOL)</td>
<td>528.58 (229.95)</td>
<td>608.27 (102.94)</td>
</tr>
<tr>
<td>TA</td>
<td>76.66 (35.53)</td>
<td>88.18 (29.94)</td>
</tr>
<tr>
<td><strong>More impaired limb MG intramuscular fat (%)</strong></td>
<td>19.92 (12.51)</td>
<td>21.96 (12.97)</td>
</tr>
<tr>
<td><strong>Less impaired limb MG intramuscular fat (%)</strong></td>
<td>18.45 (12.83)</td>
<td>20.87 (11.63)</td>
</tr>
<tr>
<td><strong>Passive fascicle stiffness (k)</strong></td>
<td>0.56 (0.44)</td>
<td>0.42 (0.19)</td>
</tr>
<tr>
<td><strong>Passive ankle stiffness (k)</strong></td>
<td>0.09 (0.02)</td>
<td>0.08 (0.02)</td>
</tr>
<tr>
<td><strong>Ankle stack angle (PF degrees)</strong></td>
<td>16.30 (11.37)</td>
<td>22.47 (11.21)</td>
</tr>
<tr>
<td><strong>Fascicle stack length (mm)</strong></td>
<td>45.83 (7.05)</td>
<td>51.23 (6.64)</td>
</tr>
<tr>
<td><strong>Isometric strength (N/m)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PF</td>
<td>67.39 (32.42)</td>
<td>90.51 (26.41)</td>
</tr>
<tr>
<td>DF</td>
<td>9.28 (4.47)</td>
<td>13.69 (7.73)</td>
</tr>
<tr>
<td>Normalized isometric strength (N·m·mL$^{-1}$)</td>
<td>0.17 (0.01)</td>
<td>0.17 (0.03)</td>
</tr>
<tr>
<td>Ankle angle at maximum isometric PF strength ($)</td>
<td>$-17.38$ (5.80)</td>
<td>$-16.11$ (5.49)</td>
</tr>
<tr>
<td>Ankle angle at maximum isometric DF strength ($)</td>
<td>$10.06$ (4.50)</td>
<td>$8.67$ (10.44)</td>
</tr>
</tbody>
</table>

**Power**
- Peak MPST (W) 304.07 (289.53) 389.19 (269.55) 330.08 (289.26) 361.08 (260.70)
- Mean MPST (W) 242.43 (221.59) 344.41 (240.93) 272.29 (231.92) 340.23 (241.32)

**Agility**
- 10 × 5 m shuttle (s) 28.86 (10.33) 24.77 (8.98) 25.00 (8.08) 24.42 (8.92)

**Functional strength**
- 30sRM total score (repetitions) 69.00 (37.39) 83.78 (34.35) 103.63 (40.97) 86.44 (37.30)

**Timed stairs**
- Time up-stairs (s) 4.38 (2.13) 3.24 (0.43) 3.30 (0.85) 3.10 (0.41)
- Time down-stairs (s) 5.48 (4.50) 2.99 (0.56) 3.80 (2.72) 2.86 (0.61)

**Walking ability**
- 6-MWT distance (m) 500.35 (145.09) 543.46 (139.90) 530.91 (124.67) 521.41 (133.36)

*Table available for intervention group (n = 6), control group (n = 3). MG, medial gastrocnemius; MPST, muscle power sprint test; LG, lateral gastrocnemius; SOL, soleus; total PF, summed muscle volume of medial gastrocnemius, lateral gastrocnemius, and soleus; TA, tibialis anterior. Functional strength, summed score of 30 s repetition maximum for lateral step-up, lung, and sit-to-stand; 6-MWT, 6 min walk test; 30sRM, 30 s repetition maximum; negative ankle angle represents dorsiflexion.
Combined strength training and BoNT-A in CP

Combination of strength training and BoNT-A injections (onabotulinum neurotoxin A)

- Reduction of spasticity.
- Significant increases in muscle strength.
- Significant increase muscle volume
  - Strength training before BoNT-A injection
  - Strength training after BoNT-A injection

<table>
<thead>
<tr>
<th>Muscle group</th>
<th>Muscle volume change (cm³/cm)</th>
<th>Pre BoNT-A training</th>
<th>Post BoNT-A training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstrings</td>
<td>0.49 ± 0.46*</td>
<td>0.60 ± 0.40*</td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td>1.63 ± 0.84*</td>
<td>1.82 ± 1.18*</td>
<td></td>
</tr>
<tr>
<td>Plantar Flexor</td>
<td>0.78 ± 0.99*</td>
<td>1.01 ± 0.35*</td>
<td></td>
</tr>
<tr>
<td>Dorsi Flexor</td>
<td>0.23 ± 0.21*</td>
<td>0.24 ± 0.15*</td>
<td></td>
</tr>
</tbody>
</table>

Mean group change in Muscle Volume over 6-months, * p<.05

Williams et al., 2013
Anaerobic and aerobic training

• 2 days/week, 32 weeks
  – Performed at school
  – 45 min session

• Exercise circuit:
  – Running, agility, step-ups, stairs
  – Anaerobic exercises = 8
    • 20-30s per exercise
  – Aerobic exercises = 8
    • 3-6 mins per exercise

↑ Aerobic capacity
↑ Functional capacity
↑ Strength

Table 2. Differences Between T0 and T2 Outcome Measures for the Training Group and Control Group

<table>
<thead>
<tr>
<th>Difference T0-T2, Mean (SD)</th>
<th>Training Group</th>
<th>Control Group</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body function and structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>0.7 (2.1)</td>
<td>0.3 (1.1)</td>
<td>.51</td>
</tr>
<tr>
<td>Aerobic capacity: level on 10-m shuttle run test, min</td>
<td>2.4 (1.9)</td>
<td>-0.4 (1.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Anaerobic capacity: mean power, W</td>
<td>20.4 (38.0)</td>
<td>-4.8 (28.2)</td>
<td>.004</td>
</tr>
<tr>
<td>Agility: 10 × 5-m Sprint Test</td>
<td>-4.5 (4.1)</td>
<td>0.2 (4.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Muscle strength left</td>
<td>6.9 (7.2)</td>
<td>-1.9 (8.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Muscle strength right</td>
<td>7.7 (9.0)</td>
<td>-1.9 (10.0)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Verschuren et al., 2007
Functional power training

• Functional anaerobic exercises
• High velocity movement
• Loaded
• Short duration

Exercises
• 14 weeks
• 3 x week
• 60min session
  • Warm up
  • Power exercises
  • Game

Van Vulpen et al., 2017
## Functional power training

### Table 4. Pre, Post, and Follow-up Values (Means and SD) for Walking Capacity and Muscle Strength Variables.

<table>
<thead>
<tr>
<th></th>
<th>Pre 1*</th>
<th>Pre 2*</th>
<th>Posttraining*</th>
<th>Follow-up*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Walking capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle Power Sprint</td>
<td>6.9 (2.9)</td>
<td>7.1 (3.0)</td>
<td>5.6 (2.1)</td>
<td>5.8 (2.0)</td>
</tr>
<tr>
<td>Average time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle Power Sprint</td>
<td>33.0 (23.7)</td>
<td>31.2 (22.8)</td>
<td>57.1 (39.2)</td>
<td>52.0 (36.7)</td>
</tr>
<tr>
<td>Mean power (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle Power Sprint</td>
<td>41.0 (29.4)</td>
<td>37.3 (26.5)</td>
<td>67.4 (48.0)</td>
<td>60.8 (43.8)</td>
</tr>
<tr>
<td>Peak power (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-Minute Walk (m)</td>
<td>74.1 (16.6)</td>
<td>73.4 (15.2)</td>
<td>82.3 (12.8)</td>
<td>82.2 (12.5)</td>
</tr>
<tr>
<td>Shuttle Run Test I and II (min)</td>
<td>7.0 (3.3)</td>
<td>6.3 (3.0)</td>
<td>9.8 (4.1)</td>
<td>8.4 (3.5)</td>
</tr>
<tr>
<td>GMFM-66</td>
<td>78.2 (7.9)</td>
<td>78.1 (7.9)</td>
<td>83.6 (7.1)</td>
<td>83.5 (8.0)</td>
</tr>
</tbody>
</table>

### Functional capacity

*Van Vulpen et al., 2017*

### Strength

*Pre 1 is at the start of the 14 weeks usual core period. Pre 2 is at the end of the of the usual core period, which is also the start of the 14-week functional power-training period. Posttraining is at the end of the functional power-training period, which is also the start of the 14-week follow-up period. Follow-up is at the end of the 14-week follow-up period.

*Most and least affected leg was determined by using the modified Trost’s SMC test for selective motor control for the ankle dorsiflexion possibility.

*Tested with Wilcoxon signed-rank test.*
Gait training

- 4hrs/day, 6days/week
- 8 weeks
- NMES-assisted gait
  - ‘Walk Aide’
  - Stimulated dorsiflexion during swing

† Strength
† Muscle volume (TA: 23%)

Pool et al., 2016
Neural component to strength

- Voluntary activation ↓ 20-50% (Stackhouse, Binder-Macleod, & Lee, 2005; Hussain et al., 2014; Rose & McGill, 2005).
- Explains 57% of PF strength (Hussain, 2014).
- Selective motor control and GMFM-66 are strongly correlated (Noble, 2018).

(Hussain et al., 2014) p<0.001
Exercise and physical activity recommendations for people with cerebral palsy

OLAF VERSCHUREN¹ | MARK D PETERSON² | ASTRID C J BALEMANS¹,³ | EDWARD A HURVITZ²
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Frequency</th>
<th>Intensity</th>
<th>Time/duration</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dodd et al.(^{44})</td>
<td>n=21 Age 8–18y GMFCS level I/II/III</td>
<td>Three times a week</td>
<td>Three sets of 8–12 repetitions to fatigue</td>
<td>6wks</td>
<td>Multi-joint exercises (heel raises, half squats and step-ups)</td>
</tr>
<tr>
<td>Liao et al.(^{45})</td>
<td>n=20 Age 5–12y GMFCS level I/II</td>
<td>Three times a week</td>
<td>One set of 10 repetitions at 20% 1RM One set of repetitions until fatigue at 50% 1RM One set of 10 repetitions at 20% 1RM</td>
<td>6wks</td>
<td>Multi-joint exercises (sit-to-stand) loaded (using weight vest)</td>
</tr>
<tr>
<td>Lee et al.(^{46})</td>
<td>n=18 Age 4–12y GMFCS level I/II/III</td>
<td>Three times a week</td>
<td>Two sets of 10 repetitions</td>
<td>5wks</td>
<td>Multi-joint exercises (squat to stand, lateral step up, stair up and down) loaded (using weight cuffs), single joint exercises</td>
</tr>
<tr>
<td>Scholtes et al.(^{38})</td>
<td>n=51 Age 6–13y GMFCS level I/II/III</td>
<td>Three times a week</td>
<td>Three sets of eight RM</td>
<td>12wks (6wks of PRE)</td>
<td>Multi-joint exercises (leg press) and loaded (using a weight vest)</td>
</tr>
<tr>
<td>Taylor et al.(^{48})</td>
<td>n=48 Age 14–22y GMFCS level II/III</td>
<td>Two times a week</td>
<td>Three sets of 10–12 repetitions</td>
<td>12wks</td>
<td>Weight machines</td>
</tr>
<tr>
<td>Maeland et al.(^{47})</td>
<td>n=12 Age 27–69y GMFCS level II/III</td>
<td>Three times a week</td>
<td>Four sets of 12–15 repetitions (week 1–2) Four sets of 4–6 repetitions (week 3–8)</td>
<td>8wks</td>
<td>Seated leg press (single joint)</td>
</tr>
<tr>
<td>Garber et al.(^{29}) &amp; Faigenbaum et al.(^{43})</td>
<td>Two to three times a week</td>
<td>One to three sets of 6–15 repetitions of 50%–85% RM</td>
<td>8–20wks</td>
<td>Single and multi-joint exercises</td>
<td></td>
</tr>
</tbody>
</table>

GMFCS, gross motor function classification system; RM, repetition maximum; PRE, progressive resistance exercise.
<table>
<thead>
<tr>
<th>Frequency</th>
<th>2–4 times a week on non-consecutive days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>1–3 sets of 6–15 repetitions of 50%–85% repetition maximum</td>
</tr>
<tr>
<td>Time</td>
<td>No specific duration of training has been identified for effectiveness. Training period should last at least 12–16 consecutive weeks</td>
</tr>
<tr>
<td>Type</td>
<td>Progression in mode from primarily single-joint, machine-based resistance exercises to machine plus free-weight, multi-joint (and closed-kinetic chain) resistance exercises. Single-joint resistance training may be more effective for very weak muscles or for children, adolescents or adults who tend to compensate when performing multi-joint exercises, or at the beginning of the training</td>
</tr>
</tbody>
</table>
Overview: Training Interventions

- Variability in exercise dose and modality.
- Strength training is safe.
  - ↑ muscle volume and strength
  - Overall health benefits
- Impact on gross motor function → combined is promising

Increase physical activity
- Reduce early functional loss
- Muscle preservation throughout life
Applying the science: practical early interventions for muscle and cardiovascular health in children / young adults with CP
Physical Activity 5

The pandemic of physical inactivity: global action for public health

Harald Wiholm Jr, Cora Lynn Craig, Estelle Victoire Lambert, Shigero Inoue, Jasmin Ramasamy Alkandari, Gert Leetongin, Sonja Kahnow, for the Lancet Physical Activity Series Working Group

Abstract

Physical inactivity is the fourth leading cause of death worldwide. We summarise present global efforts to counteract this problem and point the way forward to address the pandemic of physical inactivity. Although evidence for the benefits of physical activity for health has been available since the 1950s, promotion to improve the health of populations has lagged in relation to the available evidence and has only recently developed an identifiable infrastructure, including efforts in planning, policy, leadership and advocacy, workforce training and development, and monitoring and surveillance. The reasons for this late start are myriad, multifactorial, and complex. This infrastructure should continue to be formed, intersectoral approaches are essential to advance, and advocacy remains a key pillar. Although there is a need to build global capacity based on the present foundations, a systems approach that focuses on populations and the complex interactions among the correlates of physical inactivity, rather than solely a behavioural science approach focusing on individuals, is the way forward to increase physical activity worldwide.

The Relationship Between Body Mass Index and Gross Motor Development in Children Aged 3 to 5 Years

Deborah Norvik, PT, MHS, DP, DNS, PCS; Kacylyr Martin, PT, DNS; Peter Rasnakep, PT, PhD; Joshua Cleland, PT, PhD; Franklin Pierce University, Concord, New Hampshire (De Nervik and Cleland); and Reamur School of Physical Therapy, University of Indianapolis, Indianapolis, Indiana (De Martin and Rasnakep).

Purpose: To investigate the relationship between obesity and gross motor development in children aged 3 to 5 years using the Pediatric Developmental Motor Scales, 2nd edition (PDMS-2). Pearson chi-square and stepwise linear hierarchical regression were used for analysis. Results: A total of 24% of the 150 children overweigthed/obese, whereas 76% were found not to be overweight/obese. Fifty-one percent of the children scored above average on the PDMS-2 compared to 15% of the nonoverweight/obese group. Association between BMI and gross motor quotients was identified with significance of $p = 0.02$. Regression results were nonsignificant with all 20 subjects, yet showed significance ($p = 0.01$) when an outlier was excluded. Conclusions: Children aged 3 to 5 years with high BMIs may have difficulty with their gross motor skills. Further research is needed. (Pediatr Phys Ther 2013;25:144–149) Key words:
Chronic diseases and conditions—such as heart disease, stroke, cancer, type 2 diabetes, obesity, and arthritis—are among the most common, costly, and preventable of all health problems. 
https://www.cdc.gov/chronicdisease/overview/index.htm

Inactivity or insufficient activity
Overweight or obesity
Inadequate fruit and vegetable intake
Major modifiable risk factors for Chronic conditions
AIHW 2016
In Australia

In America:

• Percentage of children with obesity has tripled since the 1970s

• In 2015-16, 1 in 5 school children and young people in the USA were obese
Australian Physical Activity and Sedentary Guidelines

Australian Physical Activity and Sedentary Guidelines

What are the benefits?

Being physically active and limiting sedentary behaviour every day is important – it can help you to be fit and healthy and to feel good.

**SOCIAL BENEFITS**
- Creates opportunities for fun with friends.
- Reduces anti-social behaviour, including aggressive and disruptive actions.
- Develops cooperation and teamwork skills.

**EMOTIONAL AND INTELLECTUAL BENEFITS**
- Improves self-esteem and confidence.
- Helps you manage anxiety and stress.
- Improves concentration.

**HEALTH BENEFITS**
- Promotes healthy growth and development.
- Builds strong muscles and bones.
- Improves physical fitness, including coordination and movement skills.
- Reduces your risk of disease and unhealthy weight gain.

Did you know that being physically active helps you do better at school? A+

How much physical activity does my toddler or pre-schooler need?

**RECOMMENDATION**
Toddlers (1 to 3 years) & Pre-schoolers (3 to 5 years)
Toddlers and pre-schoolers should be physically active every day for at least three hours, spread throughout the day.

Physical Activity and Sedentary Behaviour Guidelines

**PHYSICAL ACTIVITY**
- For health benefits, children aged 5-12 years should accumulate at least 60 minutes of moderate to vigorous intensity physical activity every day.
- Children’s physical activity should include a variety of aerobic activities, including some vigorous intensity activity.
- On at least three days per week, children should engage in activities that strengthen muscle and bone.
- To achieve additional health benefits, children should engage in more activity – up to several hours per day.
What about kids / young adults with CP?
In Australia

19.4% ambulant children with CP coming for 3-D gait analysis in Melbourne are overweight or obese (based on BMI for age)

*Pascoe et al. 2016*
Adolescents / Adults with CP – What’s known?

• Have 2-3 x risk of death from all cardiovascular events – incl. ischaemic heart disease / cerebrovascular disease

• Overweight/obese adolescents with CP have a higher prevalence of dyslipidemia, hypertension, and fatigue than age- and weight-matched individuals without CP

• By middle age (40–60 years), adults with CP have a multi-morbidity prevalence of nearly 60%, 1.5–2.9 x higher than general population of middle-age adults.
Concept of ‘normal-weight obesity’

- Normal BMI but increased body fat
- Phenotype likely present in up to 30 million Americans & strongly correlated with cardio-metabolic dysregulation, metabolic syndrome, and CV risk factors.
- In women, NWO independently associated with increased risk for CV mortality.

Adults with CP – potentially at higher risk of NWO due to lower bone mass and decreased muscle mass
BMI poor marker of cardio-metabolic risk in adults with CP

Waist: hip ratio  (a marker for visceral fat) does correlate with markers of cardio-metabolic risk
- TChol to HDL-C ratio ($r =0.45; P< .05$),
- HDL-C ($r= −0.51; P<.01$), and TG ($r=0.40; P<.05$)
Muscle mass in CP

Individuals with CP have lower limb mass c.f. TD peers and this difference is greater as the BMI increases.

At 40Kg, 13% reduction in LL mass

At 80KG 27% reduction in LL mass
Activity levels in children and youth with CP

Bjornson 2007 Phys Therapy
March 87(3); 248-260

Carlon SL, Taylor NT, Dodd KJ, Shields N. Disability Rehab 2013

Bjornson 2014: Disability and Rehab
2014; 36(15): 1279-1284
Hemiplegia, GMFCS level II - a Typical Weekday

Activity > 80 steps/min

Activity 30 – 80 steps/min

Activity <30 steps/min
Hemiplegia, GMFCS level II – A Typical Weekend

Saturday

Activity > 80 steps/min

Activity 30 – 80 steps/min

Activity <30 steps/min

Saturday 05.10.2008 4,573 Steps
During adolescence gross motor function capacity and gait efficiency decline *Hanna 2009*
Older children with CP, all GMFCS levels, less steps per day compared with younger children *Stevens 2010*
Decline in walking skill and endurance in adults with CP showing 52% deterioration in ambulation by age 37; Fatigue, inefficiency of gait and pain. *Oppenheim 2009*
Maintaining your average number of strides per day > 30/min is associated with accomplishment of life skills (personal care, mobility recreation) *Bjornson 2013*
Muscle changes with aging

- Non-CP population:
  - Muscle strength peaks in 2\textsuperscript{nd} or 3\textsuperscript{rd} decade, with gradual decline in 5\textsuperscript{th} decade onwards (due to diminished activity) and acceleration of loss after 65.

- CP-population:
  - Have lower fitness and less muscle mass than TD peers and thus start off with reduced reserve in adulthood.
  - Documented inability to maximally recruit target muscles during exercise / over-recruitment of antagonists, leading to energy inefficiency and fatigue.
  - Premature decline in function in adulthood common with loss of ambulation.
Multi-morbidity in adults with CP

Near normal life expectancy for adults with CP

Highlights the importance of “early” health related physical activity and nutrition in childhood

http://yourcpf.org/adults-with-cp/
Reversing /preventing the changes

1. **Lifestyle strategies to decrease sedentary behavior** and reduce chronic health risks

2. **Physical activity strategies** to increase preservation of function

3. **Structured exercise strategies** to induce specific physiologic / morphologic adaptations
Reversing /preventing the changes

1. **Lifestyle strategies to decrease sedentary behavior** and reduce chronic health risks

2. **Physical activity strategies** to increase preservation of function

3. **Structured exercise strategies** to induce specific physiologic / morphologic adaptations
Sedentary behaviour

- Defined as any activity involving sitting, reclining or lying down at home, in the car, at work and during leisure time that has an energy expenditure of < 1.5 MET

- “Consistent relationship b/w self-reported sedentary behavior with incr. mortality and weight gain from childhood to adult yrs”

- Increases risk of chronic diseases / mortality in adults indpdt of BMI and physical activity levels

Sedentary Behaviors and Subsequent Health Outcomes in Adults
A Systematic Review of Longitudinal Studies, 1996–2011
• In summary, children and adults with CP spend 76–99% of their waking hours being sedentary.
Sedentary behaviour

- On average, Americans sit 11 hours a day and spend 2 hours per day watching TV

- Increased sitting or lying down behaviors in CP

- How to decrease sedentary behaviours?
  - life-style change for the whole family
  - increase activities such as standing / slow walking / lifting small objects
Decreasing Sedentary Behaviours
Reversing /preventing the changes

1. Lifestyle strategies to decrease sedentary behavior and reduce chronic health risks

2. **Physical activity strategies** to increase preservation of function

3. Structured exercise strategies to induce specific physiologic / morphologic adaptations
Incr. Physical Activity?

- < 18% of children and adults with CP engaged in light physical activities

- Only 2–7% engaged in moderate to vigorous activities (and that was only present in GMFCS levels I–III)

— Verschuren et al 2016
Increasing Light Physical Activity in CP

• Often, the baseline is close to zero

• However “The dose–response relationship between volume of moderate and vigorous aerobic activities and all-cause mortality is non-linear, with the most rapid reduction in risk occurring at the smallest increased increment of activity volume, among the most sedentary individuals.

• Thus, for people who participate in extremely high volumes of sedentary behaviour and are also completely inactive .... even small increases in the volume of activity may lead to profound health gains.”
Increasing Light Physical Activities

- For individuals who are severely deconditioned, **an effective training prescription balances appropriate training stress (at the right training intensity) with adequate recovery.**

- Initial dose of activity should include relatively low intensities and of limited duration, with sessions spread throughout the day and week.

- For example: breaking up sitting for 2 minutes, every 30 - 60 minutes e.g. transitioning from seated to standing position contributes to the accumulation of ‘light activity’. 
Reversing /preventing the changes

1. Lifestyle strategies to decrease sedentary behavior and reduce chronic health risks

2. Physical activity strategies to increase preservation of function

3. Structured exercise strategies to induce specific physiologic / morphologic adaptations
• People with CP should have moderate-to-vigorous physical activity for 60 minutes, 5 days a week or more
Vigorous physical activity (VPA)

- TD children accumulate most VPA through sport.

- Reduced participation in sport among children with CP, even among those with minimal impairments, contributes to low levels of VPA.

- Personal and environmental factors that act as barriers to participation in sport include
  - fear of exclusion,
  - fear of losing,
  - the perception that sport isn’t fun
  - a lack of teams that cater for children with a disability.

- These barriers to participation potentially decrease habitual VPA.
Increasing Cardio-vascular Health

- Children with CP who had lower levels of cardiorespiratory fitness also had higher BMI, greater central adiposity, and elevated blood pressures.

- From activity monitoring, only percentage time spent in vigorous physical exercise (not light or moderate) correlated with better cardiorespiratory fitness.

- Significant implications for the prescription of physical activity in children with ambulatory CP.
Cardio-respiratory Endurance Training

- Should be at least two to three times per week and include:
  - Regular purposeful exercise engaging major muscle groups in rhythmic activity (running, step-ups, swimming, propelling a wheelchair, arm ergometry exercises, recumbent stepping)
  - an intensity between 60% and 95% of peak heart rate, or between 40% and 80% of the HRR, or between 50% and 65% of VO2 peak;
  - a minimum time of 20 minutes per session, for at least eight consecutive weeks, when training three times a week, or for 16 consecutive weeks when training two times a week.

- A pre-workout warm-up and cool-down could be added to reduce musculoskeletal injury.
Resistance Training

• Resistance exercise
  – Frequency 2–4 times a week on non-consecutive days
  – Intensity 1–3 sets of 6–15 repetitions of 50%–85% repetition maximum

• Time
  – No specific duration of training has been identified for effectiveness. Training period should last at least 12–16 consecutive weeks

• Type
  – Progression in mode from primarily single-joint, machine-based resistance exercises to machine plus free-weight, multi-joint (and closed-kinetic chain) resistance exercises.
  – Single-joint resistance training may be more effective for very weak muscles or for children, adolescents or adults who tend to compensate when performing multi-joint exercises, or at the beginning of the training
Future considerations for **muscle health**

1. Mechanisms of growth

2. Requirements for muscle growth
   - Recovery
   - Nutrition – protein, carbohydrate
   - Supplementation

3. Maintenance of adaptations
   - Detraining
Participation, both a means and an end: a conceptual analysis of processes and outcomes in childhood disability

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This review outlines a conceptual approach to inform research and practice aimed at supporting children whose lives are complicated by impairment and/or chronic medical conditions, and their families. ‘Participation’ in meaningful life activities should be an essential intervention goal, to meet the challenges of healthy growth and development, and to provide opportunities to help ensure that young people with impairments reach their full potential across their lifespan. Intervention activities and research can focus on participation as either an independent or dependent variable. The proposed framework and associated hypotheses are applicable to children and young people with a wide variety of conditions, and to their families. In taking a fresh ‘non-categorical’ perspective to health for children and young people, asking new questions, and exploring issues in innovative ways, we expect to learn lessons and to develop creative solutions that will ultimately benefit children with a wide variety of impairments and challenges, and their families, everywhere.
The ‘F-words’ in childhood disability: I swear this is how we should think!

P. Rosenbaum* and J. W. Gorter*†

A fun & memorable way to apply the ICF Framework in practice
Thank you

Please feel free to contact us with comments and questions!

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- **AusCP-CTN CRE Associate Investigators:** Dr Lee Barber, Prof Peter Davies, Dr Andrea Guzzetta, Dr Sarah McIntyre, Dr Leanne Sakzewski, A/Prof Anthony Smith, Prof Robert Ware, Dr Koa Whittingham, A/Prof Ray Russo.

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