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Locomotor Training in the Pediatric Spinal Cord Injury Population: A Systematic Review of the Literature

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Background

Currently there is very little evidence to support the natural progression of recovery in children with spinal cord injury (SCI) leaving the restoration of walking ability an increasingly important goal in physical therapy. Locomotor training (LT) is a rehabilitation strategy that aims to restore both walking and postural control after an SCI. This strategy uses functional training with the goal of facilitating activity-dependent neuroplasticity by providing sensory input to the damaged nervous system. Through neuroplasticity, neurons in the central nervous system change their structure and function in response to development, learning, or injury. Several different types of LT exist, including body weight supported treadmill training and robotic, which aim to provide appropriate afferent information for the desired motor pattern.

Purpose

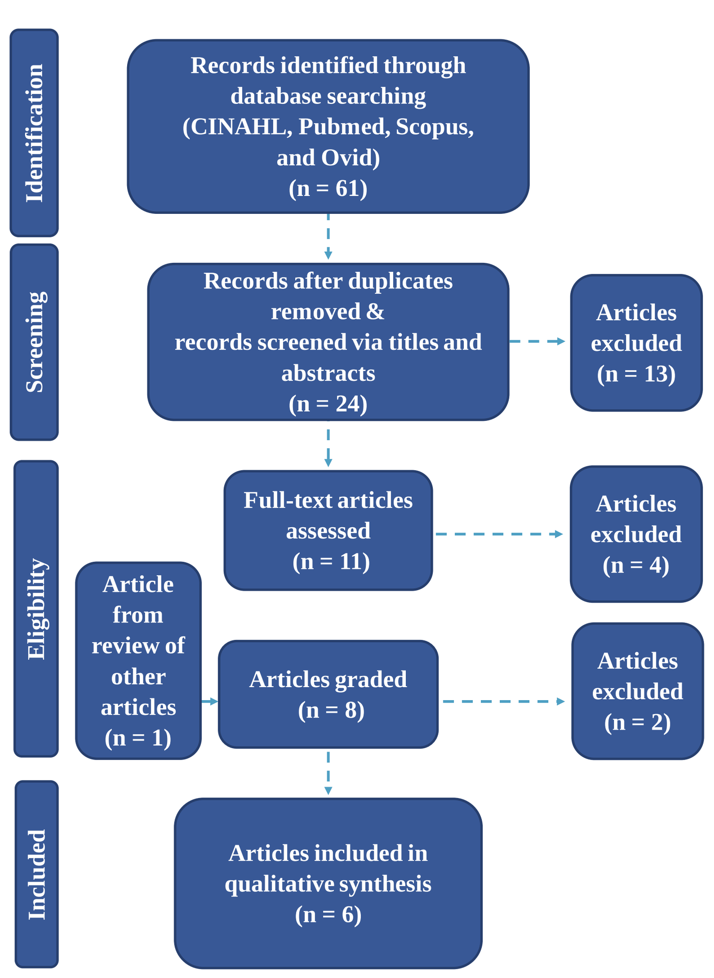
The aim of this review was to investigate the effects of LT on pediatric SCI and develop recommendations for pediatric LT guidelines.

Methods

Preliminary Search

- **Databases Searched**: PubMed, Scopus, Ovid, and CINAHL
- **Search terms**: children, pediatric, locomotor training, gait training, treadmill, spinal cord injury
- **Search Conducted**: individually by the five primary authors

Article Selection



Inclusion Criteria	Exclusion Criteria
Human studies	Abstracts
English language	Poster presentations
Published in last 10 years	Book chapters
Pediatric populations	Adult studies
Spinal Cord Injury	Inability to distract specific pediatric data
Forms of locomotor training	

Evaluation of Quality and Risk of Bias

A risk of bias assessment was performed using the Downs and Black checklist, which was developed to assess methodological quality of both randomized and non-randomized research studies. The final six studies were graded by three students and the faculty research advisor. Discrepancies between article scores were determined through discussion and resolved via research group consensus.

Participant Characteristics

Authors	Study Design	Subjects (N)	Age/Gender	Injury Level	Time from Injury to Intervention
Behrman (2008)	Case Report	1	4.5yo/M	C8 AIS C	16 months
Behrman (2012)	Case Report	3	15yo/M 14yo/M 14yo/M	T5 AIS D T5 AIS C C2 AIS D	98 days 11 months 4 months
Fox (2010)	Case Report	1	4.5yo/M	C8 AIS C	21 months
Prosser (2007)	Case Report	1	5yo/F	C4 AIS C	1 month
Hornby (2005)	Case Report	3 (1 SCI)	13yo/F	C6 AIS C	6 weeks
O'Donnell (2013)	Case Report	1	17yo/M	T6 AIS C	16 months

Note: First Author (year), yo = year old, M = male, F = female, SCI = spinal cord injury, *NeuroRecovery Network (NRN) provides a standardization of client interactions across clinical sites. A detailed description of the program has been published previously(18) **Follow-up was 1 month (baseline), 1 year, and 2 years following locomotor training sessions provided in Behrman et. al 2008.

Methods

Intervention Descriptions

	Behrman (2008)	Behrman (2012)	Fox (2010)	Prosser (2007)	Hornby (2005)*	O'Donnell (2013)
Intervention	BWSTT & OG Training	BWSTT, OG Training, Community Reintegration	F/U to Behrman et. al (2008)	BWSTT & OG Training	Robotic & Therapist-Assisted BWSTT	BWSTT & OG Training
Frequency & Duration	76 sessions	**Participant 1:** 75 sessions **Participant 2:** 293 sessions **Participant 3:** 40 sessions	10 sessions of daily LT done at 1 & 2 yr. F/U examination.	**BWSTT:** ~72-96 sessions **OG Training:** 10wk post-BWSTT, 3-4x/wk	**Robotic:** 24 sessions **Therapist Assisted:** 36 sessions	12 sessions
Time Spent Walking	**Treadmill:** 20-30 minutes **OG Training:** 10-20 minutes	**Participant 1 and 2:** 20-30 minutes **Participant 3:** 40-56 minutes	No LT done between initial LT & F/U	**BWSTT:** 10 for 3 sessions, then ~20 minutes for remaining.	**Total Walking Time:** 21-30 minutes	**First Session:** 20 minutes **Final Session:** 33 minutes
Walking Speed	0.3 → 0.6 → 0.8 → 1.2m/s	**Participant 1:** RW: 0.16 → 1.06m/s; No AD: 0-1.01 m/s **Participant 2:** RW: 0-0.38m/s; BSPC's: 0-0.45m/s **Participant 3:** No AD: 103-1.72m/s	**Baseline:** 0.45m/s **1 yr:** 0.50m/s **2 yr:** 0.67m/s	**BWSTT:** 0.27 → 0.35-0.45 → 0.45-0.54 → 0.67-0.80 → 0.80-0.98 → 0.98-1.12 m/s **OG Training:** ND	**Robotic:** 0.29m/s **Therapist:** 0.55m/s	**First Session:** 15m/min **Final Session:** 23 m/min
% BWS	40-50% → 30-40% →15-20%	**P1:** 50-0% **P2:** 50-35% **P3:** 20-5%	Ind. amb. with reverse RW, no BWS necessary.	80% → 50-52% →40% → 28-34% → 18-22% →10%	**Robotic:** 75-43% **Therapist:** 43-15%	50%
# of Therapists	3	3	N/A	2	1	3
Training Principles	ST using BWSTT followed by OG. Each 5 minute bout of ST was followed by 5 min. of standing. BWS was decreased to promote loading.	Max. WB on LEs; Optimize sensory cues; optimize proper kinematics and posture; min. compensation	Balance, Transfers & UE Strength Training; Reciprocal Walking; Reassessment of stepping.	Parameters used were for LT using treadmill and BWS with incomplete SCI typically seen in adults.	**Robotic**: Speed: 0.5-0.7 m/s Distance: pt tolerated or limited to 1000m BWS: minimized **Therapist**: Speed: up to 1.4 m/s Distance: pt tolerated or limited to 1000m	60-minute session; Start with BWSTT then progress to 20-60 minute OG Training.

Note: First Author (Year); BWSTT = Body Weight Supported Treadmill Training; OG = Over-ground; FU = follow-up; LT = locomotor training; ~ = approximately; yr. = year; wk = weak; x/wk = times per week; m/s = meters per sec; m/min = meters per minute; % = percentage; ST = step training; BWS = Body Weight Support; max. = maximize; min. = minimize; s/p = status post; SCI = spinal cord injury; ND = not documented; → = to; RW = rolling walker; AD = assistive device; ind. = indepedent; amb. = ambulation, UE = upper extremity; pt. = patient; BSPC's = bilateral straight canes. *In Hornby (2005), patients were able to begin therapist assisted BWSTT once they were able to generate normal stepping kinematics & upright posture with PT assist x1, if they were unable to meet these requirements robotic training was performed for the remainder of the session.

Results

Outcome Measures and Results by Study

<table>
<tr><th></th><th colspan="4">Behrman (2008)</th><th colspan="2">Behrman (2012)</th><th colspan="3">Fox (2010)</th><th colspan="4">Prosser (2007)</th><th colspan="2">Hornby (2005)</th><th colspan="2">O'Donnell (2013)</th></tr>
<tr><td>Participants (N=7)*</td><td colspan="4">1</td><td colspan="2">3</td><td colspan="3">1</td><td colspan="4">1</td><td colspan="2">1</td><td colspan="2">1</td></tr>
<tr><td>Time of Assessments</td><td colspan="4">Baseline & 16wk F/U</td><td colspan="2">Baseline, Every 20 sessions, D/C, 6mo F/U, & 12mo F/U</td><td colspan="3">Baseline—1mo post-Behrman (2008), 1yr F/U, & 2yr F/U</td><td colspan="4">Baseline, 1mo F/U & 6mo F/U</td><td colspan="2">Baseline, 8wk F/U & 20wk F/U</td><td colspan="2">Baseline, 2d post-6wk Training & 12wk F/U</td></tr>
<tr><td rowspan="2">ISNCSCI Scores</td><td>UEMS</td><td>LEMS</td><td>LT</td><td>PP</td><td>UEMS</td><td>LEMS</td><td>LEMS</td><td>LT</td><td>PP</td><td>UEMS</td><td>LEMS</td><td>LT</td><td>PP</td><td colspan="2">LEMS</td><td colspan="2">LEMS</td></tr>
<tr><td>"NT"</td><td>NC</td><td colspan="2">Varied</td><td>↑ (n=1)</td><td>↑</td><td>↓</td><td colspan="2">Varied</td><td>↑</td><td>↑</td><td>↑</td><td>↑</td><td colspan="2">↑</td><td colspan="2">↑</td></tr>
<tr><td rowspan="2">Gait Speed (m/s)</td><td colspan="2">GaitMat II</td><td colspan="2">BWS% ∴ Treadmill Speed</td><td>10MWT</td><td>BWS% ∴ Treadmill Speed</td><td colspan="3">GaitMat II & GAITRite</td><td colspan="4">BWS% ∴ Treadmill Speed</td><td>10MWT</td><td>BWS% ∴ Treadmill Speed</td><td>BWS% ∴ Treadmill Speed</td><td>10MWT, TUG</td></tr>
<tr><td colspan="2">↑</td><td colspan="2">↓ ∴ ↑</td><td>↑</td><td>↓ ∴ ↑</td><td colspan="3">↑ & ↑</td><td colspan="4">↓ ∴ ↑</td><td>↑</td><td>↓ ∴ ↑</td><td>↓ ∴ ↑</td><td>↑</td></tr>
<tr><td rowspan="2">Distance</td><td colspan="4">Step Watch</td><td colspan="2">6MWT</td><td colspan="3">Step Activity Monitor</td><td colspan="4">Distance Measured</td><td colspan="2">6MWT</td><td colspan="2">6MWT</td></tr>
<tr><td colspan="4">↑</td><td colspan="2">↑ (n=2), ND (n=1)</td><td colspan="3">↑</td><td colspan="4">↑</td><td colspan="2">↑</td><td colspan="2">↑</td></tr>
<tr><td rowspan="2">Walking Independence</td><td colspan="4">WISCI-II</td><td colspan="2">Step Adaptability</td><td colspan="3">WISCI-II</td><td colspan="4">WISCI-II</td><td>FIM-LMS</td><td>WISCI-II</td><td colspan="2">WISCI-II</td></tr>
<tr><td colspan="4">↑</td><td colspan="2">↓ Assist Seg (n=2), ↓ BWS%</td><td colspan="3">NC</td><td colspan="4">↑</td><td>↑</td><td>↑</td><td colspan="2">↑</td></tr>
<tr><td rowspan="2">Participation</td><td colspan="4"></td><td colspan="2">Community Reintegration</td><td colspan="3"></td><td colspan="4">Parent/Participant Self-Report</td><td colspan="2"></td><td colspan="2">PedsQL 4.0</td></tr>
<tr><td colspan="4"></td><td colspan="2">↑</td><td colspan="3"></td><td colspan="4">↑ Home, School & Community</td><td colspan="2"></td><td colspan="2">↑</td></tr>
</table>

Note: First Author (Year), * = same participant for Behrman (2008) & Fox (2010), wk = weeks, D/C = discharge, mo = month, F/U = follow-up, d = day ISNCSCI = International Standards for Neurological Classification of Spinal Cord Injury, UEMS = upper extremity motor score, LEMS = lower extremity motor score, LT = light touch, PP = pin-prick, BWS% = body weight percet, ∴ = therefore, 10MWT = 10-Meter Walk Test, TUG = Timed Up & Go, WISCI-II = Walking Index for Spinal Cord Injury, Assist Seg = assisted body segments, FIM-LMS = Functional Independence Measure - Locomotor Subscale, PedsQL 4.0 = Pediatric Quality of Life, "NT" = Not Testable, NC = No Change, ↑ = increase, ↓ = decrease. BWS% decreased therefore treadmill speed increased

Discussion

- The results of the discussed studies indicate that the pediatric SCI population can benefit from LT.
- Several measured parameters indicate that participants made gains in the ability to ambulate, regardless of change in the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) level.
- No clinically best guideline for the pediatric population can be determined from this review, however, it's worth noting the similarities and the differences among the studies that may have impacted patient progression.
  - Five of the six studies focused on segmental control and the ability of the participant to maintain proper trunk, pelvis, and lower extremity alignment
  - As a patient's independence in trunk alignment and limb position increased, BWS decreased. As BWS decreased and segmental independence increased, gait speed also increased, allowing for a more normalized walking speed and functional gait pattern.
  - Every participant also progressed to a change in environmental practice at some point in his or her treatment (e.g. over-ground training).
- In the pediatric population, the nervous system is continuously developing, therefore, the adult guidelines for LT in the SCI population must be altered to fit the needs of the pediatric population.
- It can be noted from this review that improvements in ambulation can be seen even when initiated in the chronic phase of injury disputing the "sooner the better" philosophy.
- Principles of neuroplasticity can help explain the comparable gains seen across various treatment implementations, as it appears most important to simply participate in task-specific treatment regimens.

Limitations

- No randomized control trials
- Small, specific participant population with bimodal age distribution(4.5-5 yrs. and 13-17yrs.)
- Lack of a standardized protocols for the pediatric population
- Questionable reliability when using the ISNCSCI classification system in the pediatric SCI population
- Varying time period between injury and intervention
- No consistency among outcome measures with many not being tested for reliability in the pediatric population

Conclusions

Currently, studies investigating the benefits of LT in pediatrics with SCI are based on results found within the adult SCI population. Presently, there are no established guidelines specifically for the pediatric population. While this review showed positive results for gait speed, distance, and participation, further research is needed to determine whether or not prior level of ambulation and time since injury plays a role in the ability to regain function following a SCI. Future research designs should utilize controlled researched trials to determine a causal relationship between LT and the return to ambulatory function.

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