State of the Art: Locomotor Training

Amie Lamoreaux Hesbach

EmpowerPhysio, Maynard, Massachusetts, USA, amiehesbach@gmail.com

1. Locomotor Training and Definitions

Locomotor training (LT) includes: body weight support treadmill training (BWSTT), "conventional" overground gait training (COGI), community ambulation training, and advanced gait training activities. These therapeutic activities are not successful on their own, but require knowledge, experience, and skill for appropriate selection, planning, and progression of the intervention to ensure a positive and desirable outcome for the patient.

Body weight support treadmill training (BWSTT) includes body weight support with a harness or sling system on a treadmill platform which allows for repetitive practice for motor learning. Manual facilitation by a therapist or PROM or AAROM provided by a robotic system provide sensory input to promote neuroplasticity.

Conventional over ground training (COGI) requires strong limb movement, the ability to support body weight in an upright position, and the use of specialized equipment and custom orthotics if necessary to improve the quality of the gait pattern and independence.

Community ambulation is the ability to walk independently outside of one's home, including in public and private spaces. This component of LT is appropriate as a home program for the client and patient.

Advanced gait training includes training of gait variables including different speeds, directions, and terrains (stairs, inclines, uneven surfaces) as well as refinement of motor control and quality of movement.

Goals of LT are to:
- Relearn and reinforce functional patterns of movement,
- Normalize muscle tone,
- Improve cardiovascular endurance,
- Enhance proprioception and kinesthesia,
- Approximate real-world conditions,
- Facilitate neural pathways associated with stepping movements,
- Enhance muscle activation and coordination,
- Promote recovery of function, and
- Progress from BWST to COGI to independent walking.

BWSTT is a beneficial and efficient means of performing gait or locomotor training. The patient tends to be more confident and less fearful due to the treatment environment feeling more safe and secure than when performing LT overground or in a "real world" environment. The BWSTT system frees the therapist's hands and eyes, to allow for more responsiveness

and real-time assessment of quality of postures and movements, with or without an assistive device. The therapist can correct gait deviations while the patient's trunk is secure and stable. The treadmill provides more rhythmic, cyclical activity to activate CPGs and a faster speed with more repetition for motor learning. As the limb passively moves into extension by means of "riding" the treadmill, flexor muscle groups are elongated, wound-up, and stretched to facilitate the initiation of the swing phase. The BWSTT improves weight acceptance and weight bearing tolerance, quality of over-ground walking ability, and speed, cadence, muscle coordination, rhythm, distance, and step length.

BWSTT is not universally beneficial to all SCI patients as it is not a "real world" environment and only allows straight line walking, without any perturbation training for dynamic balance. Due to the harness and sling support, the trunk is supported, thus reducing the activation and strength necessary by trunk muscles. These considerations remind the therapist of the importance of selection of the appropriate intervention for the individual patient at the patient's specific stage of recovery.

2. Locomotor Training and Central Pattern Generators

Locomotor training is essential in the rehabilitation of pets who are deep pain negative to stimulate Central Pattern Generators (CPGs). CPGs are small, autonomous neural circuits or networks that generate a rhythmic, stereotypically patterned, cyclical, coordinated, and sequential motor output in the absence of a rhythmic sensory input. CPGs are responsible for reflexive walking, swimming, flying, breathing, and chewing and are in the thoracolumbar or lumbosacral spinal cord, cervical spine, or caudal hindbrain, also known as the spinal cord transition zone. Researchers theorize that motoneurons in this transition zone, also known as the mesencephalic locomotor region (MLR), burst rhythmically, activating the descending reticulospinal system and a chain of CPGs along the spinal cord. Control of the muscle activation timing and coordination is modified in response to sensory/afferent feedback and descending supraspinal input (Buchanan 2018). CPGs include rhythm and pattern generators with characteristic, rhythmic, patterned, cyclical timing of muscle activation of synergistic muscle groups for intra-limb segment motion, and/or inter-limb coordination. It is understood that forelimb movements may facilitate and trigger hind limb stepping, therefore, suggesting that quadruped ambulation in a BWSTT environment might be more effective than biped (ie., two limbs on the treadmill/dynamic, two limbs off the treadmill/static).

Research regarding LT and CPGs includes:
- Weigel et al 2005: Investigators examined Treadmill Walking (TW) and Over Ground Walking (OGW). TW had increased stance time and stride length and maximum joint flexion at a lower velocity when compared to OGW. TW with a 0-10% incline had no significant difference in joint motion. TW with a >10% incline had a 3 degree increase in mean maximum hip extension, 4 degree increase in mean maximum hip flexion, and 3 degree increase in mean maximum hock extension and flexion. There was no difference in swing time or maximum extension, flexion, and ROM angles between TW and OGW. If the therapeutic goal is to increase weight bearing on an affected limb (with similar joint angle excursions, but less rapid joint motion), TW is a good option.
- Bundonis 2003 studied human patients with incomplete SCI. 91% of the PT+LT group were walking by end of the study while 50% of those in the PT only group were walking by end of the study.

- Schindl et al 2000 studied non-ambulatory human patients with cerebral palsy who performed LT (BWSTT) x 25 minutes x 3 days x 12 weeks. 8 of 10 had improved transfer and/or ambulation ability by the end of the study.
- Dobkin et al noted no significant long term (>3 month) difference between BWSTT and COGI.
- Field-Fote and Roach noted no significant difference in walking speed between BWSTT and COGI, though the COGI group had increased walking distance abilities.
- Wernig and Muller (1992 and 1994) when studying the walking ability of human patients with incomplete SCI after LT compared to traditional PT, noted higher gains with LT and that LT "effectively stimulates sensory receptors necessary for inducing and facilitating CPG's."
- Kobravi et al (2017) studied rats with SCI. They performed LT with epidural stimulation (40Hz continuous x20 minutes x5 days/week x1 month) then separated the rats into a quadruped and a biped group. The quadruped group was allowed to crawl or creep on the treadmill but did not have BWS. The biped group had BWS with an upper body harness. The quadruped group had increased input to CPGs and improved locomotion when in the cage (unrestricted) environment.

In a review (Chunxiao 2017) of walking ability of patients with SCI after aquatic therapy (AT) intervention, the following was found:
- 10 weeks of AT and PT (3x/week, 20 minutes) led to improved functional independence.
- 16 weeks of AT (swimming) and PT (2x/week, 45 minutes) led to improved functional independence
- 8 weeks of UWTM (3x/week, 50 minutes) led to improved walking ability.
- 16 weeks of AT and PT led to improved walking ability and maximal voluntary muscle contraction.

3. Locomotor Training and Neuroplasticity

The underlying goal in LT is to promote neuroplasticity. The research has touched on this, linking the effects of sensory input/stimulation/feedback with LT on CPGs and neuroplasticity:
- Gottschall and Nichols (2007) found that a change in head position or pitch alters the CPG response in decerebrate cats on an incline, decline, or level treadmill. The CPG activation in decerebrate cats has not been observed in rodents, monkeys, or humans.
- It is theorized that the effect of sensory input on CPGs can vary based on: phase of gait in which it is applied, the amount, type, and site to which the input is applied, and the neural network and routing of the neural signal that is activated.
- Getting and Dekin (1985) learned that an increased amount of sensory feedback improves the motor output resulting in functional swimming due to activation of CPGs in Tritonia diomedea (sea slugs). A weak sensory input resulted in withdrawal.
- Giuliani and Smith (1987) found that tail stimulation via a tail-pinch (tonic exteroceptive simulation) facilitated bilateral "air stepping" in spinalized cats 7 weeks post-injury.

Graziano et al (2013) passively exercised rats with SCI on a bicycle for 8 weeks. Results showed an increased levels of adenylate cyclase 1 (ADY1) and brain-derived neurotrophic factor (BDNF) in the cerebral cortex and an increased probability that cells in the deafferented hind limb cortex would respond to tactile stimulation of the forelimbs across all

cortical layers. The concern is that this is an example of forced exercise and could likely lead to stress in the subjects.

Stress response was tested in rats who were forced to run on a treadmill (Brown et al 2007). Serum corticosterone was elevated in both sexes 24 hours after exercise (in 3 of 4 groups). Corticosterone-binding globulin was higher in females and decreased after running. Body and spleen weights decreased in males (but not in females) in response to exercise. Forced running did not alter adrenal gland weights in either sex. The concern is that forced exercise might increase stress responses which we know is inhibitory to neuroplasticity.

Research regarding the influence of exercise, LT, and PT on neuroplasticity after SCI:
- Gomez-Pinilla et al (2012): Exercise provides a prophylactic neuroprotective effect on the brain for subsequent SCI in adult rats.
- Giszter et al (2007): The ability to maintain stance in the presence of controlled perturbations depends almost completely on the forelimbs. Sensory input from the forelimbs activates axial trunk musculature to improve balance through trunk stabilization and hind limb load reduction.
- Jurkiewicz et al (2007): Patients with cervical SCI showed improvement in function after exercise therapy.
- Hoffman et al (2007): Intensive, bimanual training of C6 motor-complete SCI results in functional improvement and increased cortical representation of the involved muscles.
- Rats with spinal transection were treated with sensory stimulation, with and without exercise, weight bearing (WB) and non-weight bearing (NWB). The exercise group had higher spontaneous firing rates in the sensorimotor cortex and were more likely to respond to sensory and sensorimotor stimulation of the forelimbs. This group had an increased intensity of response when compared to normal rats, demonstrating an expansion of the forelimb "cortical map" into the hindlimb "map." The WB exercise group had increased neuronal activity when compared to the NWB exercise group, demonstrating the influence of sensory input on neuroplasticity (Kao et al 2011).

The work of AGILE SCI suggests that balance is a better predictor of safe participation in walking activities than lower extremity muscle strength, spasticity, balance confidence, or metabolic efficiency. Gordon et al (2024) used a cable-driven robot that creates a movement amplification environment (MAE) during treadmill walking. The robot applies a continuous, laterally-directed, force to the pelvis that is proportional in magnitude to real-time lateral velocity. 36 patients participated in 20 sessions with the MAE robot-treadmill system with positive results. "Interventions that amplify self-generated movements (e.g., error augmentation) can accelerate motor learning by intensifying sensorimotor feedback and facilitating exploration of motor control strategies."

4. Locomotor Training Protocols

Protocols for LT can be gleaned from this research as well as through clinical experience. Martins et al 2021: Researchers tested two 7-week duration physical therapy (PT) protocols for dogs after T11-L3 hemilaminectomy (n=20). Both groups did 2 weeks of underwater treadmill therapy (UWTM) with manual facilitation followed by interferential current electrical stimulation (IFC or IES) as FES in standing. The groups were isolated to a BWSTT LT group and a COGI LT group (both with FES) for 2 weeks. All LT interventions were

progressive, increasing intensity and speed over time. All groups had improved outcomes including 90% with functional recovery and 100% with bladder function recovery. The BWSTT group had 100% recovery in 4.6 weeks. The COGI group had 78% recovery in 6.1 weeks.

The EmpowerPhysio LT protocol for SCI patients progresses from swimming to BWSTT to water walking and COGI. First the patient is supported, floating on the water, with passive movement of the body, allowing for sensory stimulation of the body through its interface with the water. The therapist applies sensory input or facilitation, progressing to from supported/assisted to independent, active swimming or treading in the water. While the patient is swimming, the UWTM is moving below the surface of the water (and out of reach of the patient's limbs) at a functional walking pace/speed, matching the rhythm of the patient's swimming strokes. The water level is lowered while the patient is swimming and the therapist is supporting the patient by a harness, preferably, as they contact the UWTM treadmill surface. The patient steps as independently as possible with BWS from the water environment. The treatment is progressed with reduced facilitation and correction by the therapist, reduced water level (BWS), and increased speed and duration of active and independent walking.

5. Outcomes

Through review of the available literature, we understand that outcomes in LT for human patients with SCI will be variable. In general:

- 50% will walk again with parallel bar gait training.
- 92% will walk again with BWSTT.
- Exoskeleton training is not as good as BWSTT.
- Stem cell therapy combined with BWSTT shows some promise.
- Epidural electrical stimulation with BWSTT is most promising.

Hornby et al (2025) notes that there is a tendency for better outcomes in LT for human neurological injury with a focus on increased amount, higher intensity, and increased variability of practice.

When summarizing the research reviewed in this presentation, there is improved success in LT if:
- LT is voluntary, self-selected, self-motivated, and non-stressful (and not forced).
- Training is timed early in the rehabilitation/recovery process.
- There is an enriched environment.
- A repetitive, rhythmic, cyclical patterning is used (eg., wheel, treadmill).
- The surface is irregular.
- Kinematics, postural alignment, and timing of movements are symmetrical and normalized.
- Training is in quadruped (eg., creeping or crawling vs. biped on treadmill)
- Stepping speed approximates a normal walking speed.
- Training is at a high intensity (eg., long duration (20-30 minutes), high repetition, high frequency).
- There is a maximal sustainable load placed on the stance limb. (BWS is appropriate.)
- Compensation is avoided.

- Sensory input/cues/stimulation/feedback is correct, appropriate, non-confusing, and appropriately timed.

References

1. Bliss M, Terry J, de Godoy RF. Limbs kinematics of dogs exercising at different water levels on the underwater treadmill. Vet Med Sci. 2022 Nov;8(6):2374-2381. doi: 10.1002/vms3.947. Epub 2022 Sep 14. PMID: 36104830; PMCID: PMC9677400.
2. Hornby TG, Moore J, Holleran CL, Henderson CE, Taking the Next Step in Neurologic Rehabilitation: Contributions of Intensity and Variability of Stepping Tasks during Locomotor Training, Physical Therapy, 2025;, pzaf005, https://doi.org/10.1093/ptj/pzaf005
3. Jackson et al. Joint kinematics during UWTM activity. Proceedings of the 2nd International Symposium on Rehab and PT in Veterinary Medicine. 2000.
4. Levine D et al. Effect of partial immersion in water on vertical ground reaction forces and weight distribution in dogs. AJVR. 2010. 71(12):1413-1416.
5. Martins Â, Gouveia D, Cardoso A, Viegas I, Gamboa Ó, Ferreira A. A Comparison Between Body Weight-Supported Treadmill Training and Conventional Over-Ground Training in Dogs With Incomplete Spinal Cord Injury. Front Vet Sci. 2021 Jul 1;8:597949. doi: 10.3389/fvets.2021.597949. PMID: 34277746; PMCID: PMC8280520.
6. Tragauer et al. Percentage of normal weight bearing during partial immersion. Proceedings of the 2nd International Symposium on Rehab and PT in Veterinary Medicine. 2000.