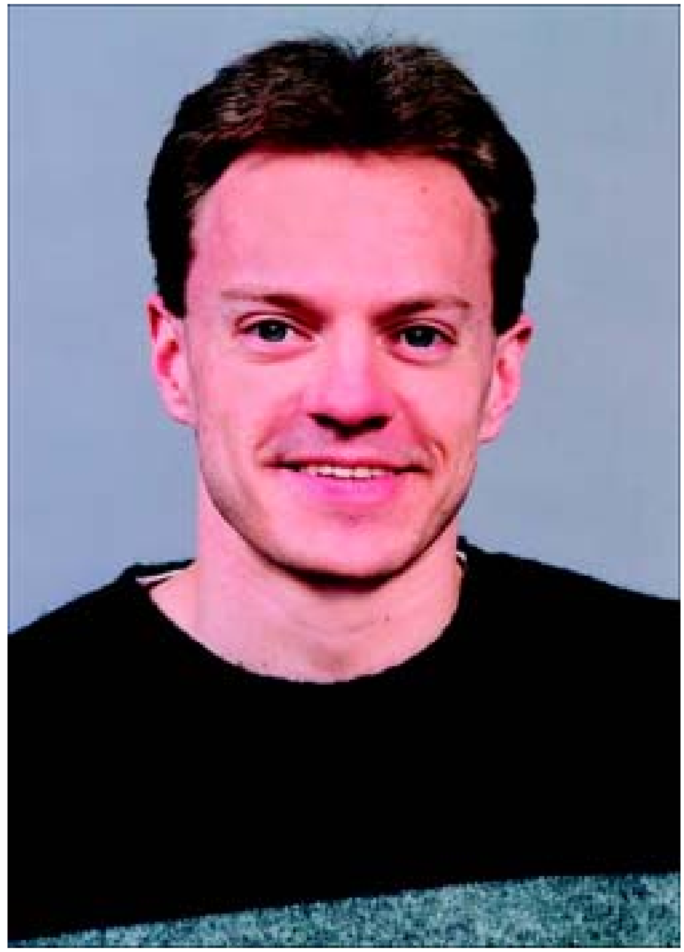
Guest Editorial

What is next for locomotor-based studies?

The scientific community has launched an aggressive campaign to investigate new therapeutic interventions that focus on restoring walking function in individuals with neurological injuries. For more than a decade now, we have seen the proliferation of scientific studies focusing on body-weight-supported locomotor training paradigms, many of which have demonstrated promising results. But where are we now? What have we learned from all of these studies and in which direction should we head next? These are the questions the scientific community needs to ask, perhaps in a large forum, so that we stop the circular nature of our investigations. With this editorial, I would like to raise a few issues that we need to examine to move this therapeutic intervention forward. Before jumping into this discussion, I want to describe some of the key concepts and findings in this field to date.

As eloquently outlined in a review by Prochazka and Yakovenko [1], we have been aware of locomotor patterns originating from segmental circuits for well more than 250 years. But the work of Sherrington [2] and Brown [3] in 1910–11 truly moved this field forward. In these studies, they found that with appropriate sensory cues from the periphery, spinalized, deafferented cats generated patterned movements that mimicked those exhibited during the flexion and extension phases of locomotion. What they originally termed “the intrinsic factor” has now become known as the central pattern generator (CPG), a cluster of neuronal networks in the central nervous system that can generate basic rhythmical motor patterns involved in tasks such as walking, breathing, chewing, and more [4]. These early studies motivated others to investigate whether appropriate training paradigms could enhance these CPGs to execute specific tasks, such as walking.

After extensive animal research demonstrated that spinalized cats can be trained to step, Barbeau and his colleagues [5] extended the concept of body-weight-supported locomotor training to humans, and since then, this area of research has taken off. Over the last 10 years, studies have shown that subjects who receive body-weight-supported treadmill training following spinal cord injury (SCI) [6–8] and stroke [9–10] demonstrate improved electromyographic (EMG) activation patterns [8,11] and more natural walking characteristics [10,12], are able to bear more weight on their legs [6], and have higher returns in functional walking ability when compared with subjects who received standard physiotherapy [7,13]. Furthermore, studies have also shown reductions in spasticity [7] and increases in cardiopulmonary



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efficiency [14] following body-weight-supported locomotor training. Note that most of these studies have focused on subjects with subacute or chronic injuries. The recently completed multicenter randomized clinical trial comparing manual-assist, body-weight-supported locomotor training with conventional gait training included a much more acute subject population (within 8 weeks post-SCI) and did not find any statistical differences between groups [15].

While these studies have laid the foundation for where we are today, it is now time to ask, "Where do we go from here?" One aspect of locomotor training that has not been properly studied in human subjects is how we should train subjects. I constantly read articles and reviews by scientists and therapists involved in locomotor training who describe the proper training paradigms, sometimes referred to as the "rules of locomotion." But the question I have always asked is, "Where did these rules come from?" Show me some quantitative evidence that supports these "rules" and you will convince me. Tell me it is based on experience, and I will listen and respect it, but I will want to see more sufficient evidence that proves these rules are true. We all know that experience and intuition by themselves do not always lead to the correct conclusion. Let me highlight just a couple of key aspects of human locomotor training that are essential, yet lack sufficient understanding.

HOW FAST SHOULD SUBJECTS BE TRAINED?

The typical treadmill training speeds used in the United States sharply contrast to those used in Europe and sometimes Canada. The philosophy of many researchers in the United States is that training speeds at or close to normal are necessary for eliciting the sensory feedback to help drive segmental circuits [16]. Those who favor this philosophy might argue that if you train too slowly, the afferent drive to the spinal cord would be reduced, effectively attenuating the locomotor pattern. In contrast, those who favor slower training speeds often argue that the subject's level of function needs to guide walking speed so that the subject can execute proper, coordinated movements without relying principally on the therapist to generate them. So, how fast should we train subjects?

Training speeds need to be set to the limit of each subject's ability to retain adequate control over leg movements. In our laboratory at the National Rehabilitation Hospital, we have found in preliminary experiments that if you train subjects too slowly, their muscle activation patterns are significantly attenuated throughout the gait cycle. Furthermore, most of our subjects report that they do not like to walk slowly because it feels more comfortable at moderate rates. In contrast, when subjects are trained too quickly, we see that the EMG patterns do get larger, but the timing of the firing patterns is so asynchronous with the movement of the legs that the subject's ability to control the leg movements is all but absent. It would be difficult to support any training paradigm in which muscle activity is lagging leg movements so that, for example, the ankle plantar flexors are highly active during midswing.

To first establish baseline training parameters for each patient and then progress training speed, we need good quantitative measures of walking ability based on joint moments exhibited by the subject as well as a solid analysis of muscle firing patterns. Without being able to quantify these behaviors, one could be misled easily into believing that certain training paradigms are facilitating locomotor patterns when, in fact, they may not be. A classic example reported throughout the literature is that training at higher speeds results in the subject stepping better, as evidenced by the reduced need for therapist assistance. But it is easy to show that at higher walking speeds, passive joint mechanics (e.g., the spring-like properties of musculotendon structures) play a progressively larger role in generating joint moments [17]. It is no wonder that subjects like training at higher speeds: They are doing less active work! This may not be the best neurorehabilitation strategy for all subjects, however, since it does not train active, coordinated control over leg movements.

While some recent evidence in the stroke literature favors higher training speeds [10,12,18–20], we need to investigate this question with larger sample sizes to determine whether there are, in fact, better outcomes across neurological populations that are statistically significant and, if so, which groups are likely to benefit most (e.g., those with initial motor deficits, lesion sites, etc.). Furthermore, one should be cautious about generalizing the findings of these studies for all neurological patients, particularly from stroke populations into SCI populations, since within 6 months, more than 85 percent of stroke subjects are walking while only 10 to 13 percent of SCI subjects ambulate within that period [21–22].

HOW MUCH BODY-WEIGHT SUPPORT SHOULD BE USED?

The amount of body-weight support is another variable, along with walking speed, that has not been adequately addressed yet profoundly influences walking ability. Visintin and Barbeau [11] first demonstrated that the timing of muscle activation patterns improved as did joint and trunk kinematics in individuals following SCI with up to 40 percent body-weight support. Harkema et al. [23] found that in a small group of SCI subjects, muscle activation patterns were modulated by loading on the lower limbs rather than by stretching the muscle tendon structure. In terms of improving walking ability, in both SCI and stroke patients, positive effects from using body-weight support during locomotor training have been reported (see Barbeau et al. for a complete review [24]).

Yet in spite of the results of these studies, we still do not know how to first establish baseline training parameters and then progress the level of body-weight support for each subject. I stress each subject because the motor deficits exhibited in most patients are quite unique, such that a training paradigm that works for one person may be quite different from those necessary for others. We have found that in SCI subjects, too little body-weight support results in significant cocontraction of antagonistic muscle groups, while too much body-weight support results in significant attenuation of EMG activity [25]. Many times, we see that providing too little or too much body-weight support results in poor, if any, ambulation. Just as with walking speed, we need to develop quantitative methods of evaluating walking performance at varying levels of body-weight support, in terms of both muscle activation patterns and joint moments. While subjects may be able to walk under heavy loads, it may be more important to train them to coordinate leg movements through properly timed muscle-firing sequences and, subsequently, active joint moments. To select training paradigms by simply looking at average muscle activation amplitudes across the entire gait cycle is insufficient, because such a method does not penalize for coactivation or poor muscle firing sequences [26].

SUMMARY

Locomotor training techniques can be improved and, consequently, better functional gains can be realized if we develop quantitative methods of evaluating walking performance, such that we can establish baseline training parameters for each patient and then progress each patient in an optimal fashion. Until now, quantitative assessments were thought to be elusive, because a standard gait analysis is not always possible, since many SCI and stroke patients do not ambulate without assistance. The instrumentation now available with gait-training robotics [27–28] makes quantitative methods possible.

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