motor pools, which include a central pattern generator for automatic, alternating flexor and extensor leg muscle activity, are highly responsive to phasic segmental sensory inputs associated with walking and demonstrate evidence of learning during step training (Edgerton et al. (1997a) Adv Neurol. 72: 233-247; Edgerton et al. (1997b). Repetitive practice of the task was essential to the learning.

[0010] Barbeau and colleagues were the first investigators to translate this paradigm to human application for retraining walking after spinal cord injury and stroke (Barbeau et al., (1987) Brain Res. 437: 83-96; Finch et al. (1991) Phys. Ther. 71: 842-855; Visintin and Barbeau (1989) Can. J. Neurol. Sci. 16: 315-325; Visintin and Barbeau (1994) Paraplegia 32: 540-553). In their initial work, Barbeau et al. (Barbeau et al., (1987) supra) suspended the consumer over a treadmill using an overhead lift for body-weight support and clinician-provided assistance to the legs.

[0011] Task-specific training appears to be critical to the success of a locomotor training intervention post-stroke (Richards et al. (1993) Arch. Phys. Med. Rehabil. 74: 612-620). Treadmill training is a method of locomotor training that closely simulates the sensory elements specific to walking such as load on the lower extremities, upright trunk posture, proper lower limb kinematics, and normal walking speeds to generate effective lower limb stepping (Edgerton et al. (1997) supra; Behrman and Harkema (2000) Phys. Ther. 80: 688-700).

[0012] Within the past 10 years, there have been many studies that have specifically investigated the effects of treadmill training with or without body weight support (BWS) on post-stroke locomotor recovery. Treadmill training (with or without BWS) appears to be more effective than conventional therapy alone in locomotor recovery after stroke (Richards et al. (1993) supra; Hesse et al. (1995a) Stroke 26: 976-981; Hesse et al. (1995b); Laufer et al. (2001) J. Rehabil. Res. Dev. 38: 69-78; Pohl (2002) Stroke 33: 553-558; Sullivan et al. (2002) Arch. Phys. Med. Rehabil. 83: 683-691). While there is building evidence that this therapeutic modality may be beneficial in improving locomotor ability after stroke, there is little agreement or systematic study of the optimal training parameters to maximize functional outcomes (Tuszynski, Edgerton, and Dobkin (1999) J. Spinal Cord Med. 22: 143). None of the current studies have incorporated abnormal muscle coactivation patterns and associated joint toques in the lower extremity. We have quantitative evidence that abnormal coupling between hip and knee extension and hip adduction exists. Furthermore, we have preliminary data that this abnormal coupling reduces the ability to generate hip abduction while stading on the paretic leg. This results then in the inability to keep the pelvis horizontal and could result in the stroke subject falling towards the affected side. As in the case of the arm, interventions that target abnormal synergistic movement patterns may ameliorate balance and greatly benefit individuals with chronic stroke-induced movement discoordination.

[0013] Implementation of current treatment philosophies is more dependent on the therapist's background and training rather than clear clinical indications or objective and quantitative measures. Furthermore, there is no consensus in the literature to support one approach over the other or even a gold standard objective measure of their effectiveness in increasing functional recovery. Heinemann et al. reported on the relationship between functional status at discharge and intensities of therapies received during the patient's inpatient medical rehabilitation (Heinemann et al. (1995) Am. J. Phys. Med. Rehabil. 74: 315-326). The results for a group of 140 patients with traumatic brain injury (TBI) identified no significant correlation between functional outcome and the intensity of therapies. The apparent lack of benefit related to intensity of therapies may be due to such factors as spontaneous recovery, lack of adequate level of intensity based on the stroke patient's absolute tolerance, and most importantly, to inadequate measurement tools, which are subjective and non-quantitative, and do not possess the discrimination power required to detect meaningful functional change. Furthermore, most current approaches may not be effective in promoting the use of more functional elbow-shoulder torque combinations because of the implementation of limited, poorly controlled exercise sequences. None of the current neurorehabilitation techniques encourage movements outside abnormal synergic patterns in a rigorous and quantifiable way.

Evidence for Motor Learning and Strength Training Capabilities Following Stroke

[0014] We have evidence from previous work that, depending on the lesion location, hemiparetic stroke subjects are able to adapt to novel force perturbations applied to their impaired arms during reaching and retrieval movements (see Krebs et al. (1996) 18th Annual Conference of IEEE-EMBS; Raasch et al. (1997) Society for Neuroscience Abstracts 23). These findings demonstrate that a considerable level of motor learning capability persists in relation to the impaired arm. We also have evidence that chronic stroke subjects are able to use the residual motor learning capability to partially regain functional elbow/shoulder torque combinations (for example, shoulder abduction/external rotation combined with elbow extension) during an eight-week training protocol (see Ellis et al. (2002a) Program No. 169.2 Abstract Viewer/Itinerary Planner. Washington, D.C.: Society for Neuroscience Abstracts; Ellis et al. (2002b) Neurology Report 26: 191, Abstract; and Ellis et al. (2003) Program No. 714 Abstract Viewer/Itinerary Planner. Washington, D.C.: Society for Neuroscience Abstracts).

The Use of Robotics in Stroke-Rehabilitation

[0015] At present, very little technology exists to support the recovery phase of stroke rehabilitation. However, there has been a surge of academic research on this topic in recent years (see, for example, Proceedings of the ICORR International Conference on Rehabilitation Robotics, 2001 and 2005). Of the academic research in progress, most research centers have elected to attempt to adapt or re-configure industrial robots for use in this application (Lum et al. (1995) Arch. Phys. Med. Rehabil. 83: 952-959). While this appears to be a reasonable approach it suffers from a critical drawback: twenty years of experience with industrial robots has shown that low impedance comparable to the human arm cannot be achieved with these machines. Because of their electromechanical design and control architecture, commercial robots are intrinsically position-controlled machines that do not yield easily under the action of external forces. Active force feedback can be used to enhance robot responsiveness but it is not sufficient to produce the "back-drivability" (low mechanical impedance) required to move