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CLINICAL PRACTICE GUIDELINES

Clinical Practice Guideline to Improve Locomotor Function Following Chronic Stroke, Incomplete Spinal Cord Injury, and Brain Injury

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ABSTRACT

Background: Individuals with acute-onset central nervous system (CNS) injury, including stroke, motor incomplete spinal cord injury, or traumatic brain injury, often experience lasting locomotor deficits, as quantified by decreases in gait speed and distance walked over a specific duration (timed distance). The goal of the present clinical practice guideline was to delineate the relative efficacy of various interventions to improve walking speed and timed distance in ambulatory individuals greater than 6 months following these specific diagnoses.
Methods: A systematic review of the literature published between 1995 and 2016 was performed in 4 databases for randomized controlled clinical trials focused on these specific patient populations, at least 6 months postinjury and with specific outcomes of walking speed and timed distance. For all studies, specific parameters of training interventions including frequency, intensity, time, and type were detailed as possible. Recommendations were determined on the basis of the strength of the evidence and the potential harm, risks, or costs of providing a specific training paradigm, particularly when another intervention may be available and can provide greater benefit.
Results: Strong evidence indicates that clinicians should offer walking training at moderate to high intensities or virtual reality–based training to ambulatory individuals greater than 6 months following acute-onset CNS injury to improve walking speed or distance. In contrast, weak evidence suggests that strength training, circuit (ie, combined) training or cycling training at moderate to high intensities, and virtual reality–based balance training may improve walking speed and distance in these patient groups. Finally, strong evidence suggests that body weight–supported treadmill training, robotic-assisted training, or sitting/standing balance training without virtual reality should not be performed to improve walking speed or distance in ambulatory individuals greater than 6 months following acute-onset CNS injury to improve walking speed or distance.

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Discussion: The collective findings suggest that large amounts of task-specific (ie, locomotor) practice may be critical for improvements in walking function, although only at higher cardiovascular intensities or with augmented feedback to increase patient's engagement. Lower-intensity walking interventions or impairment-based training strategies demonstrated equivocal or limited efficacy.
Limitations: As walking speed and distance were primary outcomes, the research participants included in the studies walked without substantial physical assistance. This guideline may not apply to patients with limited ambulatory function, where provision of walking training may require substantial physical assistance.
Summary: The guideline suggests that task-specific walking training should be performed to improve walking speed and distance in those with acute-onset CNS injury although only at higher intensities or with augmented feedback. Future studies should clarify the potential utility of specific training parameters that lead to improved walking speed and distance in these populations in both chronic and subacute stages following injury.
Disclaimer: These recommendations are intended as a guide for clinicians to optimize rehabilitation outcomes for persons with chronic stroke, incomplete spinal cord injury, and traumatic brain injury to improve walking speed and distance.
Key words: *clinical practice guidelines, locomotor function, rehabilitation*

All members of the workgroup submitted written conflict-of-interest forms and CVs, which were evaluated the Practice Committee of the ANPT and found to be free of financial and intellectual conflict of interest.

The Academy of Neurologic Physical Therapy (ANPT) welcomes comments on this guideline. Comments may be sent to locomotorcpg@gmail.com.

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Action Statement 2: VIRTUAL REALITY WALKING TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI or TBI, clinicians should use virtual reality training interventions coupled with walking practice for improving walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for individuals with stroke).

Action Statement 3: STRENGTH TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and iSCI and no evidence for individuals with TBI, clinicians may consider providing strength training to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke and iSCI).

Action Statement 4: CYCLING INTERVENTIONS FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI and TBI, clinicians may consider use of cycling or recumbent stepping interventions at higher aerobic intensities instead of alternative interventions to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke).

Action Statement 5: CIRCUIT AND COMBINED TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI or TBI, clinicians may consider use of circuit training or combined strategies providing balance, strength, and aerobic exercises to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke).

Action Statement 6: BALANCE TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. (A) Based on the preponderance of evidence for individuals poststroke and no evidence in iSCI and TBI, clinicians should not perform sitting or standing balance training directed toward improving postural stability and weight-bearing symmetry between limbs to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions. (B) Based on the preponderance of evidence for individuals poststroke and no evidence in iSCI and TBI, clinicians should not use sitting or standing balance training with additional vibratory stimuli to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions. (C) Based on the preponderance of evidence for individuals poststroke, limited evidence in TBI, and no evidence in iSCI, clinicians may consider use of static and dynamic (nonwalking) balance strategies when coupled with virtual reality or augmented visual feedback to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for individuals with stroke).

Action Statement 7: BODY WEIGHT–SUPPORTED TREADMILL TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and limited evidence in iSCI and TBI, clinicians should not perform body weight–supported treadmill training for improving walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for stroke).

Action Statement 8: ROBOTIC-ASSISTED WALKING TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and iSCI and limited evidence in TBI, clinicians should not perform walking interventions with exoskeletal robotics on a treadmill or elliptical devices to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for stroke and iSCI).

LEVELS OF EVIDENCE AND GRADE OF RECOMMENDATIONS

The American Physical Therapy Association (APTA) and the Academy of Neurologic Physical Therapy (ANPT) have recently supported the development of clinical practice guidelines (CPGs), which can be useful tools that synthesize research evidence to improve clinical practice. The goals of CPGs are to provide recommendations, based on systematic review of the literature, intended to maximize patient care through the assessment of benefit and harms, risks, or costs of various treatment options related to a specific diagnosis or outcome. These guidelines can inform clinicians, patients, and the public regarding the current state of the evidence and provide specific, graded recommendations to consider during rehabilitation to guide clinical practice. The guideline utilizes the framework delineated in the APTA Manual of Clinical Practice Guidelines to help define the levels of evidence and the development of recommendations (Tables 1 and 2).

The objective of this CPG is to provide concise recommendations regarding the efficacy of exercise interventions

TABLE 1. Levels of Evidence for Studies

LEVEL	STANDARD DEFINITIONS
I	Evidence obtained from high-quality diagnostic studies, prognostic or prospective studies, cohort studies or randomized controlled trials, meta-analyses, or systematic reviews (critical appraisal score of ≥50% of criteria).
II	Evidence obtained from lesser-quality diagnostic studies, prognostic or prospective studies, cohort studies or randomized controlled trials, meta-analyses, or systematic reviews (eg, weaker diagnostic criteria and reference standards, improper randomization, no blinding, <80% follow-up) (critical appraisal score of <50% of criteria).
III	Case-controlled studies or retrospective studies.
IV	Case studies and case series.
V	Expert opinion.

TABLE 2. Standard and Revised Definitions for Recommendations

GRADE	LEVEL OF OBLIGATION	STANDARD DEFINITIONS	REVISED DEFINITIONS
A	Strong	A high level of certainty of moderate to substantial benefit, harm or cost, or a moderate level of certainty for substantial benefit, harm, or cost (based on a preponderance of level 1 or II evidence)	A moderate to high level of certainty of moderate to substantial benefit, harm, or cost (based on a preponderance of level 1 evidence; >66% or <33% available points; recommendation: "should" or "should not")
B	Moderate	A high-level of certainty of slight to moderate benefit, harm or cost, or a moderate level of certainty for a moderate level of benefit, harm, or cost (based on a preponderance of level II evidence)	A moderate to high level of certainty of moderate to substantial benefit, harm, or cost (based on a preponderance of level II evidence; >66% available points; recommendation: "should" or "should not")
C	Weak	A moderate level of certainty of slight benefit, harm, or cost, or a weak level of certainty for moderate to substantial benefit, harm, or cost (based on level 1-V evidence)	A weak level of certainty for moderate to substantial benefit, harm, or cost (based on level I-II evidence; 33%-66% available points; recommendation: "may be considered")
D	Theoretical/foundational	A preponderance of evidence from animal or cadaver studies, from conceptual/theoretical models/principles, or from basic science/bench research, or published expert opinion in peer-reviewed journals that supports the recommendation	N/A
P	Best practice	Recommended practice based on current clinical practice norms, exceptional situations in which validating studies have not or cannot be performed, yet there is a clear benefit, harm, or cost expert opinion	N/A
R	Research	An absence of research on the topic or disagreement among conclusions from higher-quality studies	N/A

Abbreviation: N/A, not applicable.

utilized to improve walking speed and distance walked over a specific duration (timed distance) in individuals greater than 6 months following an acute-onset, central nervous system (CNS) injury. These diagnoses include individuals poststroke, motor incomplete spinal cord injury (iSCI), and traumatic brain injury (TBI), in which the initial neurological insult occurs suddenly, as opposed to progressive degenerative neurological disorders. Although published systematic reviews, meta-analyses, and other CPGs have described the potential efficacy of various rehabilitation interventions for these diagnoses,[1-7] their clinical utility and effectiveness toward facilitating changes in clinical practice is not certain. More directly, available data indicate that clinical practice patterns to improve walking function in these patient populations are not consistent with established training parameters utilized in individuals without neurological injury to enhance motor skill and function.[8-15] Although reasons underlying this lack of translation to clinical practice are multifactorial, the goal of this CPG is to detail the relative efficacy of specific interventions to improve walking speed and timed distance and employ a theoretical framework that may facilitate implementation of the recommended strategies.

The proposed CPG was designed to delineate evidence of strategies that can improve walking function, as evaluated by changes in gait speed or timed distance, with details of the rehabilitation interventions provided. These specific details are organized within the context of exercise training principles that have been thought to facilitate neuromuscular and cardiovascular alterations underlying improved motor skills and physical performance.[16,17] To our knowledge, this approach contrasts with published guidelines, systematic reviews, or meta-analyses, which often cluster studies of specific rehabilitation interventions, regardless of the details of the experimental or control intervention parameters. More directly, details of the exercise interventions, including the type, amount (duration and frequency), and intensity of practice, are often given only brief mention but may be important determinants of the efficacy of specific therapeutic strategies.[18,19] Detailing these parameters within in a CPG could equip clinicians with a better understanding of the rationale and evidence underlying specific interventions, which may facilitate their implementation.

Overview and Justification

The incidence and prevalence of acute-onset CNS injury, including stroke, iSCI, or TBI, have increased substantially in the past decades. For example, the incidence of stroke in the United States has reached nearly 800 000 per year with a prevalence of 4 to 5 million, most of whom experience mobility deficits.[20,21] For spinal cord injury (SCI), there are approximately 17 730 new cases each year, with a prevalence of approximately 300 000 in the United States alone.[22] Of this population, about 50% to 60% present with motor iSCI and therefore may have the potential to ambulate. Estimates of those with TBI vary dramatically, with up to 5 million survivors sustaining long-term neurological deficits.[23] Given the importance of physical activity and mobility on neuromuscular, cardiovascular, and metabolic function,[17] as well as on community participation,[24] effective strategies to improve walking function in these patients will be critical with an aging population.

Many interventions have been designed to improve walking function in these populations and demonstrated some level of efficacy. For example, studies that assess interventions such as neurofacilitation,[25,26] strategies that focus on specific impairments (weakness, balance, or endurance deficits)[27-29] or combined interventions,[30] and more task-specific (ie, walking) practice[24] have demonstrated positive effects. For walking interventions, however, stepping tasks practiced can vary substantially and include walking with[31,32] or without[33,34] physical assistance from therapists, with[35] or without[24] body weight support (BWS) on a motorized treadmill, walking overground,[36] stepping with robotic assistance using exoskeletal[37,38] or elliptical devices,[39] or variable walking paradigms.[40,41] Attempts to sort through these studies to identify the most effective intervention may be difficult, and meta-analyses detailing the cumulative efficacy for a particular diagnosis have been of great value. For example, recent Cochrane reviews synthesizing available literature on treadmill training[2] or robotic-assisted walking training[42] collectively reviewed approximately 450 articles to detail the relative efficacy of these interventions over alternative strategies. Similar meta-analyses are available for walking training in iSCI[6] and for overground walking poststroke,[43] with less data available for TBI. The utility of these reviews is their ability to condense data from multiple studies, with a primary goal to provide an estimated effect size for comparison to other interventions.

Although valuable, the potential problems with these reviews are highlighted by a few key issues. One concern is that meta-analyses combine data from multiple studies evaluating a specific intervention as compared with another comparison (or control) group that may not be similar in the amounts or types of therapy provided. When defining the experimental or control interventions, specific parameters such as the type, amount, and intensity are often not detailed, and these variables could influence the efficacy of exercise strategies. An example is the use of treadmill walking, as research studies utilizing this strategy vary substantially in the total number, frequency, or duration of sessions, all of which can affect the amount of practice.[34,37] Selected studies focus on increasing speeds while using a safety harness, while others provide substantial physical assistance with therapists or BWS that can influence the cardiopulmonary demands of training. Oftentimes, such interventions are provided in addition to conventional therapy, which is seldom described in detail[44] and demonstrate significant variability between studies, including no or very limited interventions, or another strategy that may vary in the type, amount, or difficulty of practice provided.[27,29] Consolidation of these data into meta-analyses may exaggerate or dilute the potential strength of any specific intervention by masking details of training that may be critical for improving outcomes.

These training variables are consistent with parameters of exercise "dose," which are speculated to impact locomotor recovery in individuals with neurological injury. More directly, data in animal models[16,45-47] and individuals without neurological injury[18,19] suggest that the *specificity*, *amount*, and *intensity* of practice are significant determinants of practice that influence changes in neuromuscular and cardiopulmonary adaptations underlying improvements in motor skills or physical performance. These training parameters are consistent with the FITT principle[17,48] (frequency, intensity, time, type), which is an established methodological consideration used in exercise prescription that can influence motor performance and physiological adaptations. In particular, "frequency" and "time" provide an indication of the total duration of practice, which can reflect the amount of specific activities if the number of repetitions of exercise is not detailed. "Type" of exercise is consistent with the specific exercise performed. Finally, "intensity" is defined as power output or rate of work (ie, workload), consistent with the exercise physiology literature, and is manipulated by altering the loads carried or movement speed. In strength training studies, intensity is estimated using the load (mass) lifted and defined as a percentage of a person's maximum load lifted for 1 repetition (1 rep max or RM). Conversely, heart rates are often used to determine exercise intensities of rhythmic movements over sustained durations (ie, aerobic activities). Although the utility of these training parameters is well established for exercise prescription for intact individuals, their utility in rehabilitation strategies to improve walking speed and distance is uncertain.[28,29] Organizing a CPG around these parameters may nonetheless help clinicians further appreciate the relative benefit or lack thereof of many exercise regimens in these patient populations.

This CPG has been developed at a potentially important time in the climate change of health care reimbursement. The Centers for Medicare & Medicaid Services), along with commercial payers of health care services, is actively seeking strategies to reduce the costs and variability in post–acute care.[49] Programs such as the Bundled Payments for Care Improvement Initiative are examples of bundling reimbursement for acute and postacute health care services designed to encourage providers to collaborate across practice settings to minimize costs and variability. These programs have been proposed and tested for a number of diagnostic groups including stroke and transient ischemia.[50] In addition, the Centers for Medicare & Medicaid Services is shifting to new models defining reimbursement for skilled nursing and home care to remove rehabilitation utilization as the primary driver of reimbursement and replace it with models defined by patient characteristics and assessments.[51,52] Furthermore, as a means to reduce health care costs and spending, payers are reducing the amount of rehabilitation services either through length of stay or number of outpatient visits. Finally, recent legislation to repeal specific therapy limitations may allow greater number of therapy visits for individuals with neurological injury. Application of evidence-based practices delineated in this CPG will assist clinicians in prioritizing delivery of services during these sessions to maximize patient outcomes and value.

Scope and Rationale

The theme of this CPG is that the efficacy of specific physical interventions applied to individuals with chronic stroke, iSCI, and TBI may be determined by the training parameters of amount, type, and intensity of task practice applied during treatment. However, specific decisions regarding the populations selected, the research articles to be incorporated, and the assessments used also influence the resultant recommendations. These decisions were determined a priori, with the rationale discussed later.

Selection of patient populations: The scope of the proposed CPG is to evaluate available evidence to improve walking function of individuals with a history of chronic stroke, iSCI, or TBI. The patient population includes adults (older than18 years) of both genders, and "chronic" injury was defined as more than 6 months following the initial injury, following which time the extent of spontaneous neurological recovery is limited,[53-57] particularly in more impaired individuals.[53,55] Focus only on individuals in the chronic stages postinjury mitigates much of the variability of motor return observed during the subacute stages of recovery (eg, <6 months postinjury). Such variability can obscure the potential benefit of specific interventions, particularly in underpowered studies. The intervention strategies described in studies are likely applied to those who have been discharged from inpatient rehabilitation and are treated in outpatient settings, skilled nursing facilities, or at home, although treatment settings vary across studies.

The rationale for combining the available data in these 3 diagnoses has been articulated in recent editorials[58-60] and utilized in selected research studies.[61-64] Although the clinical presentation of these patients can vary, all represent with acute-onset (eg, nonprogressive) damage to supraspinal or spinal pathways characteristic of "upper motoneuron" disorders. Patterns of recovery in these diagnoses include relatively consistent presentation of neuromuscular weakness and discoordination, as well as spastic hypertonia, hyperactive reflexes, and classical neuromuscular synergies. Furthermore, a fundamental tenet used to support the incorporation of all 3 diagnoses in this CPG is that principles underlying plastic changes along the neuraxis are consistent across individuals with different health conditions.[16] Specifically, changes in motor function following neurological injury may be due more to the similar neuroplastic mechanisms in spared neural pathways, or adaptations in unaffected cardiovascular or muscular systems, as opposed to separate mechanisms observed in discrete diagnoses.[58] The recommendations are detailed for these patient populations, and specific recommendations are provided for particular diagnoses with sufficient evidence available.

Selection of outcomes: The primary outcomes utilized in this CPG are gait speed and timed distance, which are strongly associated with strength, balance, peak fitness, falls, and balance confidence,[65-67] as well as selected measures of quality of life, participation, and mortality.[68,69] We are specifically utilizing measures of walking speed over shorter distances, such as the 10-m walk test (10MWT) or similar shorter-distance evaluations, and total distance walked over a sustained duration, including the 6-minute walk test (6MWT), or the 2- or 12minute walk tests. These measures of walking speed and distance have been recommended by the CPG for outcome measures to be used in neurological rehabilitation[70] and have demonstrated strong reliability, validity, and predictive value for fall risk and mortality. These specific outcome measures may limit the participant populations to those who are able to walk for abbreviated distances (eg, 10 m) and may exclude research studies utilizing primarily nonambulatory participants.

Selecting and grading evidence: In selecting specific studies for inclusion, we have focused our attention on only randomized clinical trials (RCTs) with a primary or secondary goal to improve walking speed and timed distance in the selected patient populations. Although many noncontrolled trials may extol the benefits of particular interventions, clinicians treating these patient populations have a choice of many interventions in an effort to maximize function. As such, clinicians should be provided information on the cumulative evidence regarding the strength of an intervention as compared with an alternative strategy. That is, many exercise strategies may "work" to improve walking function, although constraints in reimbursement and duration of treatment should require clinicians to more strongly consider "what works best" for the patients they treat. As such, only RCTs were considered in the present analyses to minimize bias, potential testing effects, or increased therapist or provider attention.

In addition, grading the evidence required analyses of both the experimental strategy tested and the control or comparison strategies. These comparison strategies vary widely across studies in terms of the types of intervention provided and could include a control group that consists of no intervention, an intervention that is unlikely to improve walking function (eg, upper extremity or cognitive training), or a duration-matched exercise paradigm that would reasonably be expected to improve walking. In the grading of evidence, a specific scoring rubric was developed to provide guidance when determining the strength of a recommendation to account for both the findings of the study with regard to the walking outcomes of interest and the activities provided in the control or comparison group. This scoring system is detailed further in the "Methods" section and provided an objective mechanism to account for variations in "dosage" of alternative strategies across studies (see the "Methods" section).

Target Audience

The present CPG should be useful to many rehabilitation professionals but will target primarily physical therapists and other health care providers who collaborate with therapists in the management of patients with these diagnoses. This CPG will provide clinicians with concise recommendations on the details and evidence underlying the importance of the specific exercise training parameters to improve locomotor function in individuals with chronic stroke, iSCI and TBI. With this information, clinicians should be better equipped to justify clinical application of these strategies, and subsequent efforts to implement recommended strategies could represent a paradigm shift away from current practice paradigms not recommended by research evidence.

We also anticipate that this CPG will be useful to researchers attempting to understand the relative effects of specific treatment patterns for these patient populations and for educators and students when discussing interventions for walking recovery. The recommendations of this CPG will likely be of value for health care administrators who aim to implement evidence-based strategies into their clinical setting to maximize patient outcome with limited reimbursement. Finally, this CPG should hopefully be of value to regulatory bodies and policy makers, professional associations (eg, APTA, ANPT), and third-party payers who make decisions regarding reimbursement strategies.

Statement of Intent

This guideline is intended for clinicians, patients and their family members, educators, researchers, administrators, policy makers, and payers. With continued research in the field of rehabilitation, the ongoing development and update of this guideline will provide a synthesis of current research and recommended actions under specific conditions by including new evidence as available, with consideration of patient preferences and values. This current CPG is a summary of practice recommendations supported by the available literature that has been reviewed by expert practitioners and other stakeholders. These practice parameters should be considered recommendations only, rather than mandates, and are not intended to serve as a legal standard of care. Adherence to these recommendations will not ensure a successful outcome in all patients, nor should they be construed as including all proper methods of care or excluding other acceptable methods of care aimed at the same results. The ultimate decision regarding a particular clinical procedure or treatment plan must be made using the clinical data presented by the patient/client/family; the diagnostic and treatment options available; the patient's values, expectations, and preferences; and the clinician's scope of practice and expertise.

METHODS

The development of this CPG for improving walking speed and timed distance followed a formal process and rigorous methodology to ensure completeness and transparency and ensure that standard criteria are met. The Evidence-based Document Manual released by the ANPT in 2015 served as the primary resource for the methodology utilized, with additional processes used from the updated 2018 APTA Manual of CPG Development.

The guideline development group (GDG) comprised 4 core members, all of whom were physical therapists with clinical experience in treating individuals with acute and chronic CNS injury. The administrative chair (T.G.H.) and research content expert (D.S.R.) were both faculty members within physical therapy/physical medicine and rehabilitation departments in R1 (high research activity) university systems. Both individuals possessed research experience in applied and clinical studies to evaluate changes in locomotor function in individuals with neurological injury. The clinical content expert (P.L.S.) was a clinician, administrator, and educator within inpatient, home health, and outpatient settings, and is currently a corporate clinical leader overseeing implementation strategies across a moderately sized (>200 sites) post–acute therapy provider. The CPG methodologist (I.G.W.) was a clinical practice leader at her local hospital system and is currently a research coordinator for center projects for individuals with TBI. The GDG proposed the topic to the APTA and the ANPT and selected members attended the APTA Workshop on Development of Clinical Practice Guidelines in 2014. The GDG held 5 to 6 separate conference calls to discuss the potential scope of the CPG and submitted the formal CPG proposal to the APTA Practice Committee in March 2015. Following proposal acceptance in July 2015, 2 additional physical therapists (A.M. and D.H.) were included to the GDG to assist with data extraction and database management. Two medical librarians also contributed to this project; 1 librarian completed all the literature searches to ensure consistency, while the other assisted with locating full-text articles.

Literature Search

A 2-step process for performing literature searches was adopted. A broad search was first conducted to ensure that all CPGs and systematic reviews that addressed changes in locomotor function using exercise or physical interventions for people with stroke, iSCI, and TBI were identified and reviewed for their content. In addition, the National Guidelines Clearinghouse, Guidelines International Network, and standard electronic databases (ie, PubMed, MEDLINE, CINAHL, CENTRAL) were searched to ensure that a CPG does not currently exist on this topic, and that sufficient information was available to generate a CPG. Furthermore, the GDG wished to refine the scope of the CPG by clearly identifying PICO questions (patient, intervention, control/comparison, and outcomes as detailed previously in the "Introduction" section) and relevant conceptual definitions for the proposed CPG. Secondary literature searches were conducted using more specific inclusion and exclusion criteria in prespecified databases, with a goal to obtain all RCTs published between January 1995 and December 2016. Systematic reviews relevant to interventions that may improve walking function in individuals with chronic stroke, iSCI, and TBI also served as a resource for studies. Articles were searched using key terms from each of the following categories: health condition AND intervention AND outcome. Selected interventions were searched separately (see Table 3), and specific search terms varied for each intervention to be potentially incorporated. An example of the terms utilized for the first literature search for strength or resistance training exercise is detailed in Table 3 and was initially performed in December 2015 and later in June 2017 to ensure inclusion of all articles through December 2016.

To identify potential interventions, a survey on practice preferences was used to collect information on treatment strategies used by physical therapists and physical therapist assistants in the United States (Table 4). The online survey was submitted to the ANPT and posted for 2 months on their electronic newsletter. The 14-item survey collected demographic, educational, and occupational information from 112 physical therapists and 2 physical therapist assistants, in addition to clinicians' practice preferences related to practice patterns to improve locomotor function. Approximately half (45%) of the respondents were practicing therapists for more than 15 years, and the most frequently reported practice setting was outpatient clinics (43%). Nearly all (95%) of respondents indicated that improving walking function was "very important" to "most important" to their patients. The 2 most commonly used standard tests for measuring walking function reported were the 10MWT (83%) and the 6MWT (80%). Approximately half of the respondents (49%) spend 50% to 75% of a typical session devoted to strategies to improve walking. Participants were asked to select the top 3 interventions they use to improve walking function with the following choices and frequency (percentage) described in Table 4, indicating that overground and treadmill walking and balance training were primary methods utilized. Members of the GDG also identified commonly utilized or investigated physical interventions to improve walking from the literature to ensure sufficient breadth of interventions representative of the current literature.

Search terms were created using these or associated terminology (eg, strength and resistance training). For other studies that received little attention (tai chi and vibration platform training), exercise strategies performed during these paradigms were considered sufficiently similar to balance training and were merged into the latter category. Two interventions strategies (functional electrical stimulation [FES] and aquatic therapy) were not incorporated in this CPG. Although FES is certainly utilized in specific research protocols,[71] the use of FES is also often considered a type of orthosis used to assist with ankle dorsiflexion and eversion,[72-74] and a separate ANPT/APTA-sponsored CPG for use of prosthetics and orthotics is in development. Aquatic therapy was also not incorporated because of the low

TABLE 3. Example of PICO Search Terms for Strength Training

Patient populations	stroke	"Stroke"[mh] OR stroke*[tw] OR Brain Infarction*[tw] OR Brain Stem Infarction*[tw] OR "Lateral Medullary Syndrome"[tw] OR Cerebral Infarction*[tw] OR cerebrovascular accident*[tw] OR CVA*[tw] OR subcortical infarction*[tw
	Spinal cord injury	"spinal cord injuries"[mh] OR spinal cord injur*[tw] OR "Central Cord Syndrome"[tw] OR "Spinal Cord Compression"[tw] OR Spinal Cord Trauma*[tw] OR Traumatic Myelopath*[tw] OR Spinal Cord Transection*[tw] OR Spinal Cord Laceration*[tw] OR Post-Traumatic Myelopath*[tw] OR Spinal Cord Contusion*[tw]
	Brain injury	"Brain Injuries"[Mesh:NoExp] AND "traumatic"[tw]) OR traumatic brain injur*[tw] OR traumatic brain hemorrhage*[tw] OR traumatic brain stem hemorrhage*[tw] OR traumatic cerebral hemorrhage*[tw]
Intervention	Strength training	"strengthening"[tw] OR "strength training" [tw] OR "resistance training"[mh] OR "resistance training"[tw]
Outcomes	Walking	"gait"[mh] OR "gait"[tw] OR "walking"[mh] OR walk*[tw]

Abbreviations: *, truncation symbol; picks up plurals, gerunds, etc; mh, medical subject heading; tw, the word or phrase anywhere in the title/abstract.

TABLE 4. Survey Results

Overground walking (91%)	Aerobic training (13%)
Balance (64%)	Robotic-assisted walking (8%)
Treadmill (40%)	Circuit training (4%)
Strengthening (27%)	Tai chi (1%)
Neurofacilitation (26%)	Aquatic (0%)
Functional electrical stimulation (18%)	Vibration platform (0%)

frequency of use (Table 4) and the inability to combine this intervention with other strategies.

Screening Articles

All articles returned from each search were screened to ensure that they met criteria. Two members of the GDG with content expertise (T.G.H., D.S.R.) separately performed preliminary evaluation of study titles and abstracts for potential inclusion. Their separate lists were compared and discrepancies discussed within the GDG. Articles that met initial criteria were passed to 2 other GDG members (I.G.W., P.L.S.) who reviewed the entire article to ensure appropriateness of inclusion using specific criteria, with discrepancies discussed within the GDG. Specific criteria for article inclusion were as follows: (1) participants were individuals with stroke, TBI, or iSCI greater than 6 months postinjury; (2) 1 outcome measure of gait speed or timed distance; (3) article addresses at least some parameters of interventions, including frequency, intensity, time (duration of sessions and total training duration) and types of tasks performed; (4) study uses a randomized controlled trial (RCT) design, (5) article was published from 1995 to 2016 (includes those published ahead of press in 2016), and (6) written in English language. An additional criterion was that all articles must involve more than 1 exercise session to qualify as a training study. When required, authors of articles were contacted to confirm specific information necessary for inclusion (eg, duration postinjury).

Article Appraisal

The APTA Critical Appraisal Tool for Experimental Interventions (CAT-EI) was used to appraise relevant articles. The CAT-EI comprised 3 sections (parts A to C): part A detailed general article information (eg, title, authors); part B evaluated research design and methodology, as well as specific results (outcomes); and part C assessed the impact of the study, including details on inclusion criteria, interventions, and adverse events, as well as limitations and potential biases. The level of evidence for a specific article was obtained from scoring criteria in part B, which listed 20 questions regarding methodology (12 questions) and research outcomes (8 questions). Each question was assigned a 1-point value, and the level of a study (ie, level 1 or 2; Table 1) was determined through evaluation of each reported or omitted item. The process for article appraisal using the CAT-EI was piloted by the GDG on 9 strength articles. The GDG identified items for extraction, clarified potential statements to minimize subjective decision-making in the appraisal process, and developed the appraisal manual.

The primary appraisal group was selected by the GDG to review research articles. All appraisers reviewed the manual and the CAT-EI online training video created by the APTA CPG Development Group. Each appraiser completed a practice appraisal on a sample article and subsequently reviewed 2 separate articles as "test" conditions, where scores on part B of the CAT-EI were within 2 points (ie, 10%) of the final score. Eight appraisers (4 researchers and 4 clinicians) successfully completed training and participated in guideline development. Appraisers were paired on the basis of primary employment responsibilities (1 researcher to 1 clinician). Appraisers first independently reviewed and scored each article using the CAT-EI, with data extracted as requested. Discrepancies between the reviewers in scoring or data extraction were discussed within the pairs and subsequently within the GDG if a consensus could not be reached. Articles that overlapped between intervention categories were reviewed only once but were represented in relevant categories. To minimize bias, appraisers did not review articles in which they were an author (Figure).

Formulating Recommendations

Extracted data from primary articles entered into the database were distilled into evidence tables summarizing the cumulative results for each intervention. Evidence tables included the article reference (and sample size), level of evidence and appraisal tally from the CAT-EI, participant diagnoses, results of primary walking-related outcomes, and some details regarding the intervention and the control group (including details of FITT as available, see Appendix Tables 1-8).

In addition, the evidence table included the results of a scoring rubric that was developed to quantify both the findings of the study with regard to the primary walking outcomes and the utility of the control or comparison intervention to improve walking speed or distance. Specifically, an article was assigned 1 point if the experimental intervention resulted in statistically significant gains in walking speed or timed distance as compared with the control intervention. Articles that demonstrated positive findings favoring the experimental intervention could receive a second point if the control strategy consisted of an intervention that would reasonably be expected to improve walking function, specifically incorporating volitional exercise strategies that target the lower extremity or trunk. Conversely, if the control strategies consisted of no intervention or unequal duration of therapy, or a strategy that would not be expected to improve walking, an article would not receive an additional point. Specific interventions in this latter category included arm exercises, cognitive or social activities, or passive exercises targeting the lower extremities and trunk. Each article would be assigned 0 to 2 points, and the total number of points for an experimental intervention would be used to assist with generation of the recommendation.

Articles within evidence tables were subcategorized depending upon the available evidence and specific experimental or control interventions. For example, strength training articles were subcategorized on the basis of variations

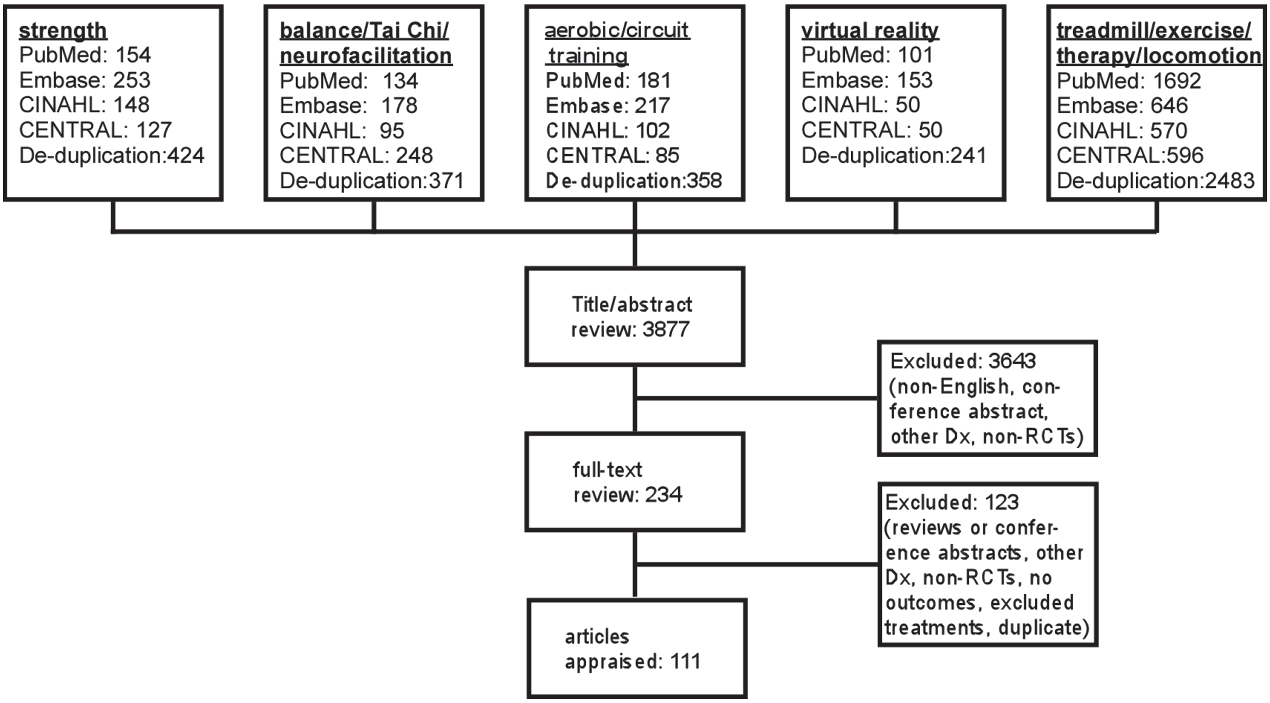

FIGURE. Flow chart for article searches and appraisals.

between the comparison groups described in each study, including those studies that provided no intervention, limited lower extremity activities (ie, passive range of motion or arm exercise), or more traditional lower extremity exercises (balance, aerobic training, etc). Conversely, balance training interventions were subcategorized by differences in experimental interventions; for example, balance activities were subcategorized as balance or weight-shifting exercises, standing or sitting activities with concurrent vibratory stimulation, or balance training with augmented visual (ie, "virtual reality [VR]") feedback. Completed evidence tables were reviewed by the GDG to minimize bias and achieve consensus.

Action statements were generated for each intervention category using Bridge Wiz APTA version 3.0.[158] Action statements were written by CPG team members with expertise in topic areas and deliberated among the GDG to minimize bias and achieve consensus. Specific criteria used to determine the strength of a recommendation were derived from published manuals from the APTA, ANPT, and Institute of Medicine, as well as the developed scoring rubric (Table 2). Recommendations for each intervention considered the quality of research articles, the magnitude of benefit, and the degree of certainty that a particular intervention can provide benefit or harm, risks, or costs. Available recommendations using standardized definitions included "strong" (A), "moderate" (B), and "weak" (C), as well as separate theoretical/foundational (D), best practice (P), and research recommendations (R; Table 2, Standard Definitions). In this CPG that incorporated only RCTs, only A to C recommendations were provided (Table 2, Revised Definitions), and theoretical/foundational premises or best practice recommendations were not utilized to minimize subjective bias. A recommendation of A to C was determined by the quality of articles, magnitude of benefit versus harm, and level of certainty as described later.

Quality of research articles: Only RCTs were included in this CPG, and all articles were rated as level 1 or 2 (ie, RCTs, Tables 1-2).

Magnitude of benefit versus harm: For this CPG, "benefit" was defined as improved walking function as indicated by significantly greater gains in walking speed or distance between experimental and comparison interventions. The extent of benefit across all articles for a particular intervention was evaluated using the scoring system described previously and further detailed later in "Degree of certainty."

Conversely, "harm" was operationalized as the potential for physical harm, risks to patient safety, and costs of each intervention. We considered the potential for physical harm or risk to patients' health with exposure to the intervention or the need to provide additional physiological monitoring to ensure safety. Such risks could include the potential risk of exercise at higher intensities in individuals with CNS injury, given the prevalence of autonomic dysfunction or history of cardiovascular disease. Additional concerns may include skin abrasion with various walking training strategies that provide direct physical contact with the limbs, orthopedic disorders for patients with altered movement strategies, and a potential increase in fall risk.

In addition, the cost of delivering the intervention was considered, which could include the cost of equipment necessary for the training (eg, treadmills, robotic systems, VR systems) or to monitor safety (eg, pulse oximeters), or costs associated with multiple trained personnel needed to perform the interventions. Additional costs across all interventions included those associated with the therapy session (eg, therapist time) and the time and travel necessary to receive a specific intervention. These latter costs were relevant considering the financial burden, time, and travel associated with an intervention that did not improve walking, which could have been utilized to provide another more efficacious intervention. Standardized terminology typically utilized in CPG development to indicate magnitude of harm, risk, or benefit is detailed in Table 2 (Standard Definitions).

Degree of certainty: To determine the degree of certainty, the results of the studies and details of the experimental and comparison interventions were evaluated using the scoring system described previously. The scores (range: 0-2 points) for all articles within an evidence table (or subcategory if relevant) were summed and divided by the total number of possible points (eg, 6 articles = 12 points). This calculated ratio assisted in determining the strength of the recommendation (ie, strong, moderate, or weak; Table 2, Revised Definitions).

The strength of the recommendation informed the level of obligation and specific terminology utilized to formulate the action statement (Table 2). A "strong" or "moderate" recommendation, designated as a high to moderate degree of certainty of benefit, resulted in a "should" recommendation; this recommendation required at least 66% (ie, two-thirds) of the available points for a given intervention. A "strong" or "moderate" recommendation that clinicians "should not" provide an intervention was indicated if less than 66% of the available points for scored research studies suggest worse or no difference in outcomes between an experimental intervention and a control intervention. A "should not" recommendation indicated a preponderance of harm, risk, or cost, given no superiority over a range of comparison interventions, particularly when other, more effective interventions were not utilized. Differentiation of "strong" versus "moderate" recommendations (A or B) was made on the basis of the percentage of level 1 articles; "strong" recommendations were provided with 50% or greater level 1 articles, whereas "moderate" was less than 50% level 1 articles (Table 2).

To assign a "weak" recommendation for an intervention, the GDG considered that 33% to 66% of available points of the evaluated studies should indicate a positive effect of the experimental intervention. That is, a "weak" recommendation suggested that the superiority of the experimental intervention is uncertain, given the potential harm, costs, and risk of providing an experimental intervention that oftentimes does not result in superior outcomes. In these conditions, the term "may" was utilized in development of the action statement. Using the developed scoring system, a "weak" recommendation was assigned if the experimental intervention was consistently better than comparison interventions consisting of no treatment, unequal duration of therapy or attention, or if the control intervention likely would not improve locomotor function, as quantified using the developed scoring system.

Given the criteria established to delineate "should," "may," and "should not" recommendations at 33% and 67% thresholds, only interventions with at least 4 research articles were provided a recommendation. These criteria were developed to reduce the likelihood a recommendation would change substantially during revision based on a single article.

Patient Views and Preferences

An important part of the Action Statements in a CPG is to identify whether, when, or where patient preferences impact decision-making. To the extent that patient views are by definition individual, shared decision making with the patients, given their preferences and the risks and benefits of the intervention, should be undertaken. Some evidence to help understand patients' views and preferences for both outcomes and interventions can be identified through recent literature[159-162] detailing perspectives from individuals who have received physical rehabilitation following acute-onset CNS injury. The available evidence suggests specific patient preferences for outcomes included being able to walk at faster speeds and being able to walk for longer distances,[163-165] consistent with the importance of locomotor function for health and mortality rates.[166] In terms of interventions, preferences for therapy sessions of shorter durations (20-60 minutes vs up to 6 hours) and low- to moderate-intensity activities have been found.[159,162] Selected literature suggests that more traditional rehabilitation regimens are sometimes preferred,[159-161] although the attraction of advanced technology and devices to assist rehabilitation may have facilitated greater use of many robotic or VR systems during rehabilitation interventions. Importantly, patients' perspectives may vary with the potential benefits gained from a given intervention. For example, in a study investigating motivators for higher-intensity treadmill training after stroke,[167] the evidence suggests that patients are motivated by the results of an intervention. This indicates that if patients are educated about the potential for better outcomes with use of a particular intervention, this could become a motivator for participating in the intervention. Potential preferences are listed in action statements as pertinent.

Expert and Stakeholder Review

Multiple panels reviewed the CPG prior to public comment including an expert panel, a stakeholder panel (individuals with stroke, iSCI, and TBI, and administrators, educators, and physicians), and the Evidence Based Document Committee of the ANPT. The expert panel included 6 researchers with expertise in postural control and balance training, strength training, rehabilitation robotics, VR, and various locomotor interventions. The stakeholder and exert panels consisted of 17 individuals with overlapping occupational responsibilities or stakeholder involvement. Specific individuals included health care administrators (n = 3), educators in entry-level or residency physical therapy programs (n = 10), and physicians (n = 3) with strong involvement in the treatment of individuals with stroke, SCI, or TBI. Researchers in the field of physical medicine and rehabilitation (n = 12) with specific expertise in the interventions addressed in this guideline were included. In addition, individuals with a history of stroke, SCI, or TBI (n = 1 each) agreed to participate. A link to the AGREE II (updated 2017) tool was sent to each reviewer. Scores from the AGREE II tool and specific reviewer comments were reviewed and the CPG was revised as possible to accommodate reviewer concerns, with responses from the GDG available upon request. The reviewed CPG was subsequently posted on the ANPT Web site for public comment and followed similar process described previously prior to submission for publication.

Knowledge Translation and Implementation Plan

General recommendations for implementation are provided with each recommendation (Implementation and Audit section under each Action Statement) and potential factors that may influence implementation provided in the Discussion. The Practice Committee of the ANPT has assembled an 8-person committee that will work on specific knowledge translation and implementation initiatives for this CPG and will collaborate with members of the CPG development team; therefore, limited information is provided in this document.

Update and Revision of Guidelines

This guideline will be updated and revised within 5 years of its publication as new evidence becomes available. The procedures for updating the guideline will be similar to those used here, using procedures based on recommended standards, and sponsored by the APTA/ANPT.

ACTION STATEMENTS AND RESEARCH RECOMMENDATIONS

Action Statement 1: MODERATE- TO HIGH-INTENSITY WALKING TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke, limited evidence in individuals with iSCI, and no evidence for individuals with TBI, clinicians should use moderate- to high-intensity walking training interventions to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for individuals with stroke).

Action Statement Profile

Aggregate evidence quality: Level 1. Based on 10 level 1 RCTs (total n = 418) examining whether moderate- to high-intensity walking training results in greater benefit than other conventional physical therapy, stretching, or low-intensity walking training. Eight of 10 articles showed differences in locomotor outcomes between moderate- to high-intensity walking training compared with low-intensity training or conventional physical therapy.

Benefits: Moderate- to high-intensity walking training performed in individuals greater than 6 months following stroke, iSCI, and TBI may benefit patients by improving walking outcomes and therapists by more rapidly assisting patients to reach these outcomes and decrease resource utilization.

Risks, harm, and costs: Increased costs and time spent may be associated with travel to attend higher-intensity walking interventions. There may be an increased risk of cardiovascular events during higher-intensity walking training without appropriate cardiovascular monitoring. There is a potential cost of equipment to monitor cardiovascular demands during evaluation and training to ensure safe participation, including also the time and potential training of qualified personnel to adequately evaluate the potential risks for individual patients. Consultation with the patient's physician should occur before implementing higher-intensity training.

Benefit-harm assessment: Preponderance of benefit.

Value judgment: Walking training appears to be effective at moderate- to high-aerobic intensities (ie, 60%-80% of heart rate (HR) reserve or up to 85% maximum HR). Cardiovascular conditioning can also address the effects of deconditioning associated with stroke.

Intentional vagueness: None

Role of patient preferences: Available evidence suggests that patients often prefer lower-intensity activities and may have difficulty maintaining higher intensities. Conversely, others may appreciate the gains in walking function with performance of moderate- to high-intensity walking training. Given the value of higher-intensity activity, patients may need to be educated on the benefits of higher-intensity interventions that they initially may not be inclined to prefer.

Exclusions: Potential exclusions include individuals with significant cardiovascular history for whom the patient's physician does not recommend participation in higher-intensity training.

Quality improvement: Individuals will receive appropriate intensities of walking training to maximize total amount of walking practice in reduced time, resulting in improved locomotor function. Therapists will be more systematic in their evaluation of patient's vital signs to improve safety and mitigate potential risks.

Implementation and audit: Challenges associated with implementing moderate- to high-intensity exercises may be the perceived barriers related to cardiovascular monitoring. Strategies for implementation include increased physiological monitoring and providing HR calculators in electronic medical record systems, as well as providing Ratings of Perceived Exertion (RPE) scales around the clinic. Providing treatment templates in the Electronic Medical Record (EMR) that require recording of HR and RPEs at regular time intervals during a treatment session would improve adherence.

Supporting Evidence and Clinical Implementation

Exercise training of rhythmic locomotor activities performed at moderate to high intensity (eg, 60%-80% of HR reserve or 70%-85% HR maximum) can lead to greater improvements in timed walking distance and measures of oxygen consumption as compared with lower-intensity exercises in a variety of patient populations without neurological compromise, including those with significant cardiovascular compromise.[168,169] These observations led investigators to question whether similar findings would be observed in individuals with CNS injury.[170] A number of studies have investigated the effects of moderate- to high-intensity walking training on walking outcomes in individuals greater than 6 months following stroke, with few in patients with iSCI.

Appendix Table 1 details the evidence describing the effectiveness of moderate- to high-intensity (ie, aerobic) training interventions. Four level 1 studies examined the effects of moderate- to high-intensity treadmill training in individuals with chronic hemiparesis poststroke compared with other more passive interventions.[34,75-77,171] In these 4 studies, participants in the experimental groups trained on the treadmill or overground 3× per week for 30 to 50 minutes per session at 60% to 80% HR reserve or 60% to 85% age-predicted maximum HR. Participants trained for 3[75,76] or 6 months.[77,171] In 2 of the studies,[34,77] participants in the control group performed stretching exercises while in the other 2 studies participants in the control group either had light massage of the affected limbs[75] or passive exercise of the limbs with some balance activities.[76] Locomotor outcomes revealed a significantly larger increase in the 6MWT in the higher-intensity training groups compared with comparison interventions in all studies. In addition, walking speed on the 10MWT was significantly greater in the experimental versus control intervention of 1 study,[75] although walking speed was not different between groups in 2 studies[34,77,171] and was not measured in another.[76]

A fifth level 1 study examined the effects of high-intensity (80%-85% of age predicted HR maximum) treadmill training performed 2 to 5× per week for 4 weeks in persons with chronic stroke who had been discharged from physical therapy due to a plateau in walking function[24] This study did not find a difference in walking speed or distance with moderate- to high-intensity treadmill training.

Three of the level I studies that compared moderate- to high-intensity walking training with low-intensity training in those with chronic stroke also found greater improvements in locomotor outcomes in the higher-intensity group.[78,79,81] Two of these studies utilized high-intensity interval training.[78,81] In the study by Boyne et al,[78] participants in the high-intensity group walked for 30-second bursts at their fastest possible speed, alternating with 30- to 60-second intervals where the treadmill was stopped. Participants in the low-intensity group walked at 40% to 45% HR reserve. Participants trained approximately 3× per week for 12 sessions with a goal of 20 to 25 minutes per session. Large effect sizes favoring the high-intensity interval group were found for walking speed. In the study by Munari et al,[81] participants trained 3× per week for 50 to 60 minutes per week for 3 months in both groups. In the high-intensity interval training, participants trained in five 1-minute intervals at 80% to 85% of $\dot{V}o_2$ peak separated by 3-minute intervals at 50% $\dot{V}o_2$ peak. In the low-intensity group, participants trained at 60% $\dot{V}o_2$ peak. Participants in the high-intensity group had greater improvements in walking speed and distance on the 6MWT than those in the low-intensity group.

Another study that found improvements with high- versus low-intensity walking training in chronic stroke used a randomized crossover design.[79] Participants were randomized to receive 12 sessions of high- or low-intensity training over 4-5 weeks, followed by a 4-week washout and subsequent initiation of the other training paradigm. Participants performed 30 minutes of treadmill and 10 minutes of overground walking at either 70% to 80% HR reserve (high intensity) or 30% to 40% HR reserve (low intensity). Participants showed greater improvements in 6MWT following high- versus low-intensity training. There were no differences between groups in changes in walking speed. However, 1 level I study in individuals with chronic stroke did not find significant improvements with moderate- to high-intensity walking training compared with low-intensity training.[80] In this study, participants in the high-intensity group trained on a treadmill at 80% to 85% of HR reserve for 30 minutes 3× per week for 6 months while participants in the low-intensity group trained at less than 50% HR reserve. There were no differences between groups in 10MWT or 6MWT.

One additional level 1 study compared low- with high-intensity training in those with chronic iSCI.[82] In this randomized crossover design, participants trained 1 h/d, 5 times per week for 2 months, and then had no training for 2 months and crossed over to the other arm of the study. High-intensity training consisted of walking on the treadmill at speeds faster than their self-selected speed and walking as far and as fast as possible with minimal rests was emphasized. The focus of this intervention was on "endurance training" on a treadmill and not necessarily achieving high intensity, although HR recordings revealed average HRs within the moderate- to high-intensity range (76 ± 7.9%; data provided by study authors). The control intervention consisted of "precision training which included walking over obstacles at different heights and onto targets of differences sizes, although was performed at lower HR ranges (mean %HR maximum = 68 ± 8.9%). The higher-intensity "endurance" training resulted in significantly higher HRs and steps per session as compared with the "precision training" at lower intensities. There were significant differences between groups in change in distance on the 6MWT but no differences in walking speed.[82]

In summary, the studies detailing the effects of walking training at moderate to high intensity received 14 out of 20 possible points (70% of 10 articles considered). Specific patient comorbidities, including uncontrolled cardiovascular or metabolic disease, musculoskeletal disease or injury, or severe neurological deficits, must be considered to allow safe participation of higher-intensity training interventions. Depending on comorbidities, a graded exercise testing with electrocardiographic assessments performed prior to implementation should be considered. Consultation with the patient's physician should occur before implementing higher-intensity training. Depending on the disease condition(s), alternatives/modifications could include performing moderate- to high-intensity cycling (ie, seated position) or use of a safety harness during walking training and graded exercise testing prior to implementation. The advantage of moderate- to high-intensity walking training is that it does not require expensive equipment, can be implemented in most clinical settings, and follows fundamental principles of exercise physiology, making it ideal for individuals who may have restricted access to specialty clinics.

Research recommendation 1: The effects of high-intensity walking exercise are fairly consistent across studies, although variations in the intensity of exercise performed warrant further consideration, and the effects and safety of achieving higher intensities above 80% HR reserve, as performed during interval training, should be assessed.

Action Statement 2: VIRTUAL REALITY WALKING TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI or TBI, clinicians should use VR training interventions coupled with walking practice for improving walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for individuals with stroke).

Action Statement Profile

Aggregate evidence quality: Level 1. Based on 6 of 7 RCTs (4 level 1, 3 level 2; combined n = 291), VR training coupled with walking practice can elicit greater improvements in walking speed or distance than other alternative interventions, including conventional physical therapy, stretching, or walking training alone.

A separate study compared VR training coupled with walking practice with a cognitive task to VR training coupled with walking practice alone.

Benefits: Virtual reality training in combination with walking training performed in individuals following chronic CNS injury improves walking outcomes as compared with walking training alone, stretching, or conventional physical therapy.

Risks, harm, and costs: Training in a virtual environment may cause dizziness. The necessary equipment may not be readily available to clinicians and/or may be expensive and these may be a barrier to implementation. Additional concerns include the use of customized VR systems in many studies, which may preclude their use in clinical settings and the lack of understanding of the specific features of the VR system that resulted in the positive outcomes.

Benefit-harm assessment: Preponderance of benefit.

Value judgment: Training in a virtual environment allows safe practice of challenging walking activities that may increase volitional engagement in a controlled setting, which otherwise may be difficult to replicate in hospital or clinical settings.

Intentional vagueness: Few studies delineated the effects of VR-coupled walking training on the physiological (HR) demands during training. The effects of specific VR systems may alter the outcomes of this recommendation.

Role of patient preferences: Individuals may prefer to utilize feedback systems during walking training to increase engagement. Alternatively, others may be hesitant to use specific technology.

Exclusions: Studies included primarily custom-built VR systems. This recommendation may not directly apply to use of commercially available VR systems.

Quality improvement: Patients may receive treadmill training using VR to mimic real-life walking conditions that cannot normally be practiced in the clinical setting. Such activities may increase the duration and tolerance of training by increasing volitional engagement and attention. Therapists may improve documentation of specific tasks that augment patient's engagement to ensure sufficient effort.

Implementation and audit: The costs and training associated with clinical implementation of VR systems will need to be justified, although selected systems may be utilized during other balance training tasks (see balance training with VR). Additional documentation and training for use of specific systems may be required to ensure that therapists adequately monitor patient's engagement.

Supporting Evidence and Clinical Implementation

Walking practice in varied environmental contexts is considered important to achieving full recovery of ambulation due to the wide variety of environmental demands encountered when walking in the community.[40,172-174] This type of practice is often difficult to achieve in the hospital or clinical setting and thus, training in virtual environments has emerged as a potential alternative. Training in a virtual environment may facilitate greater engagement within an illusion of 3-dimensional space, allowing interaction between the user and the simulated but challenging visual context through the computer interface in a safe environment.[175] Interactions with a virtual environment may increase participation and motivation to perform walking practice.[176,177]

Strong evidence indicates that VR coupled with walking practice utilized in individuals in the chronic stages following stroke, iSCI, and TBI results in gains in walking function as compared with alterative interventions (see Appendix Table 2). Five level 1 studies examined the effects of VR coupled with walking practice in individuals with chronic hemiparesis poststroke. In 4 of these studies[83-85] and 1 level 2 study,[86] participants participated in VR coupled with treadmill training compared with treadmill training alone, with both groups receiving additional conventional therapy. In 2 studies,[83,84] conventional rehabilitation also included lower extremity FES. One study[85] had a control group that completed stretching exercises in addition to conventional rehabilitation. In 3 studies,[83,84,87] VR provided during walking training consisted of community-based walking scenes including a sunny 400-m walking track, a rainy 400-m walking track, a 400-m walking track with obstacles, daytime walks in a community, nighttime walks in a community, walking on trails, striding across obstacles, and street crossing. In 1 study,[85] the VR consisted of a scene of trees on either side of a path. In the level 2 study, participants in the VR group performed dual-task grocery shopping in a virtual grocery store.[86] Participants in all studies walked on the treadmill with or without VR for 20- to 30-minute sessions, 3× per week for 3 to 6 weeks. Training intensity was not specified in any of the studies, although treadmill speed started at self-selected pace and was then progressed throughout training in each study, with parameters slightly different between studies. Resultant walking outcomes revealed a larger increase in walking speed in the VR-coupled treadmill training paradigms as compared with treadmill training alone (or control group in Kang et al[85]) in all 5 studies. In addition, distance on the 6MWT was significantly greater in the VR-coupled treadmill training groups than in treadmill training alone or control groups, although 6MWT was not used in the other studies.

One additional level 1 study[88] did not find a difference in locomotor outcomes when VR was coupled with treadmill training compared with VR coupled with treadmill training while doing cognitive tasks (memory, arithmetic, verbal tasks). In addition to conventional rehabilitation, both groups walked on the treadmill with VR for 30 minutes, 5× per week for 4 weeks. Both VR groups showed a significant improvement in gait speed pre- to posttraining, but there was no difference in this improvement between groups.

Two level 2 studies examined the effects of VR coupled with walking practice in individuals with chronic hemiparesis poststroke.[89,90] Kim et al[90] randomized participants to 1 of 3 groups. The control group consisted of usual physical therapy for 10, 30-minute sessions per week for 4 weeks. A separate community ambulation group consisted of overground walking, stair walking, slope walking, and unstable surface walking of 570 m for 30-minute sessions, 3 times per week for 4 weeks. Finally, the VR-coupled treadmill training group consisting of 4 VR conditions—sidewalk walking, overground walking, uphill walking, and stepping over obstacles for 30-minute sessions, 3 times per week for 4 weeks. Intensity of training was not specified for any group, but participants in the VR group increased speed by 5% each session if they could walk without loss of balance for 20 seconds. Walking speed and distance on the 6MWT were not different between the VR-coupled treadmill training group and either of the other 2 groups. In the other level 2 study,[89] participants were randomized to walking on a treadmill and stepping over virtual objects or walking overground and stepping over obstacles. Participants walked at their self-selected speed and in 1 session completed 12 trials stepping over 10 obstacles in each trial. Both groups completed 6 sessions over 2 weeks and participants in the VR group showed significantly greater improvements in walking speed, but there were no differences between groups in distance on the 6MWT from pre- to posttraining.[89]

In summary, the studies detailing the effects of treadmill walking training with augmented visual feedback/VR received 12 of 14 possible points (86% of 7 articles considered). Differences between methods for providing VR environments may contribute to variations in outcomes between studies. Although VR-coupled interventions appear to consistently improve walking performance, mechanisms underlying the changes observed were not well defined. Given the potential engagement with VR environments, greater neuromuscular and cardiovascular demands may have been observed, although limited physiological monitoring provides little insight into whether this was an important factor.

Research recommendation 2: Future studies should evaluate measures of total amount and intensity of training to evaluate their relative contribution to these VR-coupled walking trials. In addition, the specific VR systems used during training may differ slightly in their ability to engage patients, and their relative efficacy should be evaluated.

Action Statement 3: STRENGTH TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and iSCI, and no evidence for individuals with TBI, clinicians may consider providing strength training to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke and iSCI).

Aggregate evidence quality: Level 1. Based on 9 RCTs (7 level 1 and 2 level 2; combined n = 278) comparing strength training interventions with no exercise or other physical interventions, there was inconsistent evidence to suggest a benefit of strength training on walking speed or distance. Four studies revealed a positive benefit of strength training, whereas 5 studies revealed no benefit on walking outcomes. A separate study that compared eccentric with concentric strength training demonstrated no superiority of either intervention on walking outcomes.

Benefits: Lower extremity strength training performed in individuals greater than 6 months following stroke, iSCI, and TBI could be provided in multiple clinical settings with available equipment.

Risks, harm, and costs: Increased costs and time spent may be associated with travel to attend strength-training sessions. There may be an increased cost of strength training when specialized equipment (weight machines or dynamometers) are utilized. Potential risks may include increased hypertensive responses in individuals with cardiovascular disease, although no significant adverse events are reported beyond usual care. There is a potential cost of equipment to monitor cardiovascular demands during evaluation and training to ensure safe participation and also includes the time and potential training of qualified personnel to adequately evaluate the potential risks for individual patients.

Benefit-harm assessment: Neutral.

Value judgment: Most strength training studies utilized exercises that targeted multiple sets and repetitions of 70% to 100% of participants' 1 repetition maximum (1RM) to target a primary impairment contributing to locomotor deficits. However, gains were inconsistent across studies.

Intentional vagueness: None.

Role of patient preferences: Some individuals may prefer to exercise at lower intensities and 70% to 100% of 1RM may be difficult to achieve.

Exclusions: Potential exclusions may include individuals with significant cardiac limitations, as strength training may cause short-term elevations in blood pressure, and consultation with the referring physician may be warranted. Other considerations include significant paresis in selected muscle groups such that limitations in volitional activation may minimize the ability to perform specific strengthening exercises.

Quality improvement: Clinicians may benefit from documentation of the loads (eg, %1RM) and amounts (eg, sets and repetitions) of strength training in attempts to optimize dosage parameters consistent with published studies.

Implementation and audit: Challenges associated with implementing higher-intensity strength training may be related to equipment and perceived barriers related to cardiovascular monitoring. Strategies for implementation include ensuring appropriate equipment for persons with disabilities, including strength training devices and systems to monitor cardiovascular demands. Strategies for documenting total amount and intensity of strength training interventions may facilitate chart audit to ensure compliance.

Supporting Evidence and Clinical Implementation

Lower extremity weakness is a cardinal sign of upper motoneuron disorders and is strongly correlated with walking ability.[65,67] Decreased force or power is due primarily to deficits in volitional (ie, neural) activation of the involved musculature,[179,180] although peripheral changes in the muscle, including atrophy,[181,182] increased stiffness,[183-185] and altered fiber characteristics, have been observed.[186,187] Deficits in power generation have been linked directly to reduced walking speed,[188,189] and rehabilitation strategies designed to improve muscle strength have been suggested to improve locomotor function.[190-192] Such strategies vary from static to dynamic training with the use of dynamometers, weight machines, elastic bands or free weights (leg weights) during controlled movements, or performance of strengthening activities within the context of functional tasks (ie, sit-to-stand performance or step-ups).

Appendix Table 3 details the evidence describing the effectiveness of strength training interventions. Three level 1 articles indicate that strength exercises utilized in individuals greater than 6 months following stroke, iSCI, and TBI results in limited gains in walking function as compared with alternative or no interventions. Flansbjer et al[91] and Severinsen et al[92] evaluated the effects of strengthening exercises, consisting of bilateral knee extension and flexion or bilateral knee/hip extension flexion and ankle dorsi-/plantar flexion over 10 to 12 weeks (20-36 sessions). Following a brief warm-up, training intensity was targeted at 80% maximum volitional contractions (MVCs), and participants performed 2 to 3 sets of 6 to 8 repetitions. Control interventions in both groups consisted of no interventions, although Seversinsen et al[92] included an additional experimental group of aerobic training (three 15-minute bouts of cycle ergometry reaching 75% HR reserve over 12 weeks). Primary results of both investigations revealed no improvements in either 10MWT or 6MWT from strengthening to control groups, although Severinsen et al[92] demonstrated greater improvements in 10MWT than in aerobic training. Additional results include improvements in lower extremity strength in both studies as compared with control (ie, no intervention) groups. Potential limitations of both studies include the limited number of muscle groups trained (knee flexors and extensors).

In a separate study, Yang and colleagues[93] evaluated the effects of functional strengthening tasks (step-ups, sit-to-stand training, heel rises) in individuals with chronic stroke without use of assistive devices over 4 weeks (12 sessions) as compared with no intervention. The functional tasks were performed in a circuit training–type protocol, with specific standing exercises with attempts to reach at different distances (considered strengthening tasks by the authors), sit-to-stand training, stepping forward, backward or sideways onto blocks of various heights, and heel raises during standing. The number of repetitions was graded to each participant's functional level, and both repetitions and difficulty of tasks (eg, height of step-ups) increased as tolerated, although details were not provided. Results indicated significantly greater improvements in 10MWT and 6MWT in experimental versus comparison group. In addition, strength gains of 30% to 40% across paretic and nonparetic legs were observed in the experimental group, with negligible improvements in the control intervention. Limitations of this study include the lack of sustained follow-up assessments after training, and the potential lack of specific measures of intensity (repetitions, load, speed, sets) in the experimental training group.

Three level 1 studies evaluated the effects of lower extremity strength training as compared with range of motion exercises on impairments or functional tasks. In the study by Kim et al,[95] participants poststroke performed strengthening exercises over 6 weeks (18 sessions) targeting bilateral knee extension, dorsi- and plantar flexion forces, and whole-limb extensor power generation (ie, leg press). The comparison group performed passive range of motion exercises. In the experimental intervention, 3 sets of 10 repetitions of MVC concentric exercises performed on an isokinetic dynamometer targeted paretic hip, knee, and ankle dorsi-/plantar flexion. A measure of composite muscle strength across all paretic muscle groups demonstrated trends of significant differences from the control group ($P = 0.06$), although no differences in gait speed were observed. In the study by Ouellette et al,[96] experimental exercises targeted paretic and nonparetic dorsiflexors, plantar flexors, and knee extensors, as well as bilateral leg press exercises using 3 sets of 8 to 10 repetitions using 70% of MVCs. Control strategies targeted bilateral lower-limb strength and upper body flexibility exercises. There were no differences in gait speed or 6MWT changes between groups, with small differences in strength. In contrast, Bourbonnais et al[94] revealed greater walking and strength improvements in individuals with chronic stroke following high-intensity lower versus upper extremity strength training. Lower extremity strength training was performed in specific hip and knee positions in sitting, with both the direction and magnitude of distal forces at the foot measured and used as feedback to the patient. The participants were provided feedback to exert force in 16 different directions that required varying hip and knee activation, with the magnitude of forces starting at 40% to 60% MVCs and progressing to 70% to 90% MVCs toward the end of the 18 sessions. Limitations of these studies include the limited muscle groups tested or trained.

In 1 level 1 and 2 level 2 studies, lower extremity strengthening exercises were compared with alternative interventions. In the study by Jayaraman et al,[97] participants with iSCI enrolled in a crossover RCT, in which they performed either 4 weeks (12 sessions) of 100% MVCs (3 sets/10 repetitions) of bilateral knee extensors and flexors and dorsi- and plantar flexors or conventional strengthening strategies, including 3 sets of 10 to 12 repetitions at 60% to 75% MVCs. The results revealed positive although nonsignificant improvements in 10MWT but greater gains in the 6MWT following high-intensity training. In another crossover study by Labruyere and van Hedel,[99] lower extremity strengthening exercises performed over 4 weeks (16 sessions) was compared with robotic-assisted gait training in participants with iSCI. In the strengthening interventions, 3 sets of 10 repetitions targeting the lower extremities were performed at 70% MVC and included isotonic leg press and hip adduction/abduction as well as flexion/extension. Primary results indicate greater improvements in 10MWT with strength training versus robotic-assisted gait training. Limitations of both studies include the use of a crossover design during which the lack of washout of previous training effects may minimize gains with the second intervention performed. Finally, Kim et al[98] evaluated the effects of 40 sessions over 8 weeks of ankle strengthening exercise plus conventional therapy as compared with balance training on the Biodex Balance System plus PT. Strength training was performed in 14 participants focusing on the dorsi-and plantar flexors for 30 minutes in isometric, isotonic, or open/closed kinetic chain exercises at 70% of 1RM, although details of the number of repetitions and sets were not provided. Conventional therapy of additional balance training was provided. Forty training sessions were provided over 8 weeks. In 13 participants, balance training was performed with 9 different conditions of altered visual and audio input with perturbations on a standing platform. Gains in 10MWT favored the balance versus strength training group.

In a separate study, Clark and Patten[100] investigated in the effects of different forms of strength training over 5 weeks (ie, concentric vs eccentric) prior to 3 weeks of gait training. In participants with chronic hemiparesis poststroke, 5 weeks of high-intensity eccentric or concentric strength training of the paretic leg was performed using an isokinetic dynamometer using a triangle pyramid paradigm targeting higher speeds in the first 3 weeks and higher loads in the last 2 weeks. Specific muscles trained include knee and ankle flexion/extension as well as multisegmental tasks involved most sagittal plane muscle groups. Participants performed 3 to 4 sets of 10 repetitions at 3 different criterion speeds, with verbal encouragement. Following each strength training paradigm, gait training interventions were performed in both groups. The findings of the study indicate no significant between-group differences in walking speed following the strength and gait training interventions. Differences in strength gains were specific to the tasks performed; peak eccentric power was greater following eccentric training and peak concentric power was greater following concentric training. However, this study was not scored as it compared different strength training strategies and did not vary in other types of FITT parameters (intensity, time, frequency).

In summary, the studies detailing the effects of strength training using loads greater than 70% of 1RM received 6 out of 18 possible points (33% of 9 articles considered). The effects of strengthening exercises are relatively inconsistent in improving walking speed or distance after acute-onset CNS injury.

Research recommendation 3: Specific comparisons between higher-intensity (≥70% 1RM) strengthening interventions for multiple sets and repetitions against other task-specific (ie, walking interventions) activities should be performed to evaluate the relative efficacy of these strategies on both walking and strength outcomes.

Action Statement 4: CYCLING INTERVENTIONS FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI and TBI, clinicians may consider use of cycling or recumbent stepping interventions at higher aerobic intensities instead of alternative interventions to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke).

Action Statement Profile

Aggregate evidence quality: Level 2. Based on 5 studies (2 level 1 and 3 level 2 RCTs; combined n = 356), only 3 cycling studies demonstrated significantly greater gains in walking function as compared with other interventions.

Benefits: Cycling may improve locomotor outcomes in participants greater than 6 months following stroke, iSCI, and TBI. Available evidence suggests that such training should be performed at higher aerobic intensities.

Risks, harm, and costs: Increased costs and time spent may be associated with travel to attend cycling or recumbent stepping interventions, or equipment needed to perform such exercises. Additional risks may include increased potential for cardiovascular events during higher-intensity training cycling without appropriate cardiovascular monitoring. There is a potential cost of equipment to monitor cardiovascular demands during evaluation and training to ensure safe participation, including also the time and potential training of qualified personnel to adequately evaluate the potential risks for individual patients. Consultation with the patient's physician should occur before implementing higher-intensity training.

Benefit-harm assessment: Neutral.

Value judgment: The effects of cycling or recumbent stepping at higher aerobic intensities may provide a greater benefit than lower-intensity activities.

Intentional vagueness: The number of articles contributing to this recommendation is small. Future research regarding the efficacy of this intervention may alter the recommendations at the time of CPG revision.

Role of patient preferences: Available evidence suggests that patients often prefer lower-intensity activities and may have difficulty maintaining higher intensities. Conversely, others may appreciate the gains in walking function with performance of moderate- to high-intensity walking training. Given the value of higher-intensity activity, patients may need to be educated on the benefits of higher-intensity interventions that they may not be inclined to prefer.

Exclusions: Potential exclusions include individuals with significant cardiovascular history that may require clearance from the patient's physician to participate in higher-intensity training.

Quality improvement: Monitoring and documentation of the intensity of cycling training may improve the efficacy of treatments relative to improving walking speed and endurance.

Implementation and audit: Strategies for implementation include using devices that assist with physiological monitoring, HR calculators provided in the electronic medical systems to estimate targeted HRs, and posting charts detailing RPE scale around the clinic. Providing treatment templates that require recording of HRs and RPEs at regular time intervals during a treatment session would improve adherence. This information could then be reviewed in a chart audit to monitor adherence consistent with the guideline.

Supporting Evidence and Clinical Implementation

With chronic CNS injury, walking training is often difficult for many individuals due to safety concerns or fear of falling. Seated cycling training or recumbent stepping may be effective for improving measures of cardiovascular endurance in a variety of patient populations.[193,194] Accordingly, seated cycling and recumbent stepping have been studied as an alternative for improving locomotor outcomes such as walking speed and endurance after stroke, iSCI, and TBI.

The available evidence suggests that cycling or recumbent stepping training results in inconsistent gains locomotor outcomes in people with chronic CNS injury as compared with other exercises or lower-intensity strategies. Appendix Table 4 details the evidence describing the effectiveness of cycling or recumbent stepping training interventions. One level 1 and 2 level 2 articles showed benefits of higher-intensity cycling training compared with conventional therapy, lower-intensity cycling, or walking training in individuals with chronic stroke.[101-103]

In one level 1 study and one level 2 study, participants performed cycling exercise at 50% to 70% HR reserve, 40 minutes a day, 5 times per week for either 8 weeks[102] or 12 weeks.[103] In 1 study,[102] the control group completed matched duration low-intensity (20%-30% HR reserve) overground walking training and both groups completed balance and stretching exercises. During cycling, the paretic leg was also weighted, starting at 3% body weight and increasing as tolerated to allow completion of the task. In the other study,[103] the control group completed matched duration conventional physical therapy that included 35 minutes of stretching and 5 minutes of low-intensity walking at 20% to 30% HR reserve. In both studies, participants in high-intensity cycling showed greater improvements in 6MWT distance than the control group.[102,103]

In another level 2 study,[101] participants with chronic stroke participated in conventional physical and occupational therapy in addition to 30 minutes of high-intensity (50%-80% maximum HR) or self-selected intensity cycling 5 times per week for 4 weeks. Participants in the high-intensity cycling group showed greater improvements in 6MWT distance than those in the self-selected intensity group following training,[101] but there were no differences in 10MWT between groups.

One level 1[92] study and 1 level 2[104] study did not find greater improvement in locomotor outcomes in persons with chronic stroke following high-intensity cycling training compared with strength training. Severinsen and colleagues[92] trained individuals 3× per week for 12 weeks in a high-intensity (75% HR reserve) cycling group, high-intensity lower extremity resistance training group, or a sham (low-intensity upper extremity resistance training) group. There were no differences in walking speed on the 10MWT or distance on the 6MWT between groups following training. The level 2 study[104] compared the effects of 8 weeks of lower extremity ergometry training performed over forty 30-minute sessions at less than 40% HR reserve to VR balance training using the Xbox Kinect for a similar duration. There were no differences in changes in 10MWT between groups, with both demonstrating a decrease in gait speed, and results of other clinical balance tests demonstrating similarly small differences.

In summary, the studies detailing the effects of cycling training at moderate to high intensity received 6 out of 10 possible points (60% of 5 articles considered). This recommendation may be influenced by new studies in the next update of this CPG. Consideration of comorbid conditions that would make moderate- to high-intensity cycling training unsafe must be undertaken. Depending on comorbidities, a graded exercise testing with electrocardiographic assessments performed prior to implementation should be considered. Consultation with the patient's physician should occur before implementing higher-intensity training. The advantage of moderate- to high-intensity cycling training is that it can be implemented in almost any location and follows the basic principles of exercise, making it ideal for individuals who may have restricted access to specialty clinics.

Research recommendation 4: The data regarding the efficacy of cycling exercise on walking function suggest a potential benefit if higher-intensity exercise is performed, and further studies should evaluate the efficacy of cycling, particularly as compared with other, more task-specific (ie, walking) activities.

Action Statement 5: CIRCUIT AND COMBINED TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and no evidence for individuals with iSCI or TBI, clinicians may consider use of circuit training or combined strategies providing balance, strength, and aerobic exercises to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: weak for individuals with stroke).

Aggregate evidence quality: Level 1. Based on 8 of 10 RCTs (8 level 1, 2 level 2; combined n = 446), circuit-training strategies focused on postural stability, strength training, and locomotor tasks demonstrated improved walking function as compared primarily with interventions that did not target the lower extremities or alternative interventions.

Benefits: Circuit training or combined exercises performed in individuals following chronic CNS injury may be of benefit to improve walking outcomes compared with "sham" control groups that focus on upper extremity activities or social and cognitive tasks.

Risks, harm, and costs: Increased costs and time may be associated with travel to attend circuit-training interventions, with potentially additional costs for equipment. There is a potential cost of equipment to monitor cardiovascular demands during evaluation and training to ensure safe participation, including also the time and potential training of qualified personnel to adequately evaluate the potential risks for individual patients.

Benefit-harm assessment: Neutral.

Value judgment: The lack of data that directly compare circuit or combined training to alternative interventions that target lower extremity impairments or functional deficits limits the strength of recommendation.

Intentional vagueness: Comparison interventions detailed in most studies consist of no interventions or use of strategies that would not be reasonably expected to improve locomotor function (eg, upper extremity or cognitive tasks). Future research regarding the efficacy of this intervention compared with other strategies that may reasonably be expected to improve walking function may alter these recommendations.

Role of patient preferences: Selected individuals may prefer lower-intensity activities.

Exclusions: Potential exclusions include individuals with significant cardiovascular history that may require clearance from the patient's physician to participate in higher-intensity training.

Quality improvement: Monitoring and documentation of vital signs during training may facilitate greater implementation of higher-intensity interventions.

Implementation and audit: Strategies for implementation include using devices that track HR in real-time, providing calculators in electronic medical systems to estimate targeted HRs, and providing RPE scales around the clinic. Providing treatment templates that require recording of HRs and RPEs at regular time intervals during a treatment session would improve adherence.

Supporting Evidence and Clinical Implementation

Individuals with CNS injury often present with multiple impairments, such as weakness, postural instability, and decreased endurance or conditioning that limit their walking speed and endurance.[65,67] Many therapeutic strategies focus on individual impairments, although their efficacy may be limited when multiple impairments underling walking dysfunction are not targeted. Accordingly, training strategies that combine multiple interventions to target patients' deficits have been utilized in clinical rehabilitation of patients post-CNS injury.[195-197] Circuit training combines multiple impairment-based and functional exercises, although it is typically performed by switching between tasks with short rest periods between exercises. Many combined and circuit-training activities target relatively higher aerobic intensities, with variations in the type and difficulty of tasks performed.

The available evidence indicates that circuit and combined training focused on strength, balance, and locomotor deficits in patients greater than 6 months following acute-onset CNS injury elicits greater improvement in locomotor function as compared with no interventions, or therapy sessions that are not directed toward lower extremity impairments (see Appendix Table 5). In 6 level 1 RCTs, the effects of circuit training were evaluated in participants with chronic stroke. Dean et al[105] and Mudge et al[107] both evaluated that the effects of circuit training were compared with other activities in which no leg exercises were performed. Dean et al[105] randomized 12 individuals into either twelve 1-hour sessions of lower extremity circuit training or upper extremity exercise sessions. The experimental group performed 10 stations within the exercise circuit that included balance and strength activities, with selected walking activities, although the amount, duration, and intensity of each task practiced were unclear. Control activities focused primarily on upper extremity exercises. Similarly, in 60 participants poststroke, Mudge et al[107] compared the effects of 12 sessions of circuit training as compared with mental and social tasks on balance, strength, and walking function. Circuit training consisted of mostly balance and walking activities with no report of amount, intensity, or duration of tasks practiced, while the control group performed cognitive and social (game playing) activities. In both studies, greater improvements in 6MWT were observed in the experimental group, with gains in 10MWT only in the study by Dean et al.[105] Cardiovascular intensities were not reported in both studies.

Three circuit-training studies focused on balance, strengthening, and/or ambulation tasks, with attention to intensity of task practice. Both Pang et al[108] and Moore et al[106] recruited approximately 60 individuals poststroke to evaluate the effects of up to fifty-seven 1-hour sessions of circuit-training exercises on locomotor balance and cardiovascular function as compared with control interventions. In the experimental group, participants rotated through 3 different exercise stations of aerobic conditioning, consisting of walking and nonwalking aerobic exercise, mobility and balance training, and functioning strengthening exercises. Participants received feedback of HR responses during training and were asked to achieve up to 40% to 50% of HR reserve during the first few weeks, with intensity increased 10% until 70% to 80% HR_{max}, In both studies, control activities focused on upper extremity tasks and social interactions, with no focus on lower extremity function. Greater changes in 6MWT were observed in the study by Pang et al,[108] whereas Moore et al[106] demonstrated gains in both 10MWT and 6MWT. Additional improvements included greater gains in peak $\dot{V}o_2$ in both studies in the experimental groups, whereas the study by Moore et al[106] also observed greater gains in balance with circuit training. In addition, Vahlberg and colleagues[110] studied the effects of 3 months (2 times per week) of circuit training on walking function and body composition in 43 participants with chronic stroke. Participants in the experimental group received 1-hour circuit-training sessions using a high-intensity functional exercise program consisting of lower-limb strength, balance, and walking exercises. Intensities of exercise were monitored using RPEs, and attempts were made by participants to work at their highest intensity for 2 minutes, followed by 1-minute rest. Sitting, standing, and walking exercises were performed with resistance and/or weights around their waist to achieve higher cardiovascular demands, although no specific range of intensities achieved were provided. Participants in the control group received usual care only, with the final result indicating significantly greater gains in 6MWT and improved percentage of fat-free body mass following circuit training.

Song et al[109] evaluated the effects of additional individual versus group circuit-training activities plus convention therapy as compared with conventional therapy alone. Thirty participants with chronic stroke all received up to twenty 30-minute sessions of conventional therapy over 4 weeks and were randomized to an additional 30 minutes per session of a circuit-training program supervised by 1 therapist, additional circuit-training classes supervised by 2 therapists, or no additional training. Circuit training consisted of walking in variable contexts (around obstacles, dual physical tasks), and postural exercises in sitting, with details of the conventional therapy not described. Significantly greater improvements in gait velocity and 2-minute walk test were observed in both groups provided additional circuit training as compared with those provided conventional therapy alone, with no differences between circuit-training groups. Limitations of this study include inconsistent measures of the amount and intensity of practice of each task throughout the studies, as well as no focus on lower extremity activities in the control groups.

The effect of combined exercise therapies without use of a circuit-training paradigm has also been explicitly evaluated in 2 level 1 and 2 level 2 studies, with different tasks performed at variable intensities. Two level 1 studies[112,113,198] evaluated the effects of aerobic and strengthening or upright dynamic balance tasks at higher versus usual care or lower-intensity activities. Lee et al[112] evaluated the effects of 6 months of aerobic exercise using walking or cycling and various lower extremity strengthening exercises as compared with no exercises on locomotor function and arterial stiffness. Participants in the experimental group performed more than 20 minutes of aerobic exercises and 30 minutes of resistance training consisting of 2 to 3 sets of 10 to 15 repetitions at 11 to 16 RPE. Changes in both 10MWT and 6MWT favored the experimental training, in addition to measures of transfers and postural stability. Tang et al[113,198] compared 6 months of high-intensity aerobic training during walking, cycling, and dynamic balance activities as compared with a lower-intensity intervention in 50 individuals with chronic stroke. Participants in the experimental group received 1-hour sessions 3 days per week that consisted of 30- to 40-minute aerobic exercise during walking, ergometry, or repeated sit-to-standing, stepping on platforms, and marching in place. The desired intensity levels increased from 40% of HR reserve up to 80% HR reserve over the course of training. Participants in the control groups received similar amounts of sessions, although tasks consisted of balance and flexibility training and were performed at less than 40% HR reserve to minimize aerobic challenges. Posttraining assessments revealed no greater improvements in 6MWT in the experimental versus control group, as well as no differences in peak $\dot{V}o_2$ or measures of arterial stiffness.

In another level 2 study enrolling 13 participants with chronic stroke, Teixeira-Salmela and colleagues[114] evaluated the efficacy of 10 weeks of combined, moderate- to high-intensity aerobic and strengthening activities as compared with a wait-list control group. Following a brief warm-up period, participants in the experimental condition received 30 sessions over 10 weeks of aerobic exercises attempting to achieve 70% of maximal HR while walking, stepping, or cycling for up to 40 minutes. In addition, strength-training activities targeting hip, knee, and ankle muscle groups were performed over 30 minutes, with goals of 3 sets of 10 repetitions at up to 80% of 1RM. As compared with the control group, participants who completed the experimental paradigm revealed greater improvements in strength and subjective functional and quality-of-life measures, with changes in spasticity.

In a final study, Hui-Chan and colleagues[111] evaluated the effects of combined physical therapy exercises as compared with a group that received no interventions. During 20 sessions provided in the home over 4 weeks, participants were randomized to receive 60 minutes of physical therapy consisting of standing and walking exercises, no interventions, or these 2 interventions coupled with transcutaneous electrical nerve stimulation, the latter of which is not considered here. The results indicate very small but significant between-group differences in 10MWT and 6MWT between the exercise and no exercise groups.

In summary, the studies detailing the effects of circuit or combined training received 9 out of 20 possible points (45% of 10 articles considered). Although the collective data demonstrate significant gains in walking function following combined or circuit training, the findings are mitigated by the lack of comparisons of these strategies against matched duration of physical therapy activities that target the lower extremities or trunk. The only study to evaluate another intervention that could reasonably be expected to improve walking function did not demonstrate positive outcomes.[113]

Research recommendation 5: Future studies should consider evaluation of circuit and combined training interventions that delineate the amounts, types, and intensities of interventions compared with a matched duration therapy that could reasonably be expected to improve walking function in individuals in the chronic stages following stroke, iSCI and TBI.

Action Statement 6: BALANCE TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. (A) Based on the preponderance of evidence for individuals poststroke, and no evidence in iSCI and TBI, clinicians should not perform sitting or standing balance training directed toward improving postural stability and weight-bearing symmetry between limbs to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions. (B) Based on the preponderance of evidence for individuals poststroke, and no evidence in iSCI and TBI, clinicians should not use sitting or standing balance training with additional vibratory stimuli to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions. (C) Based on the preponderance of evidence for individuals poststroke, limited evidence in TBI, and no evidence in iSCI, clinicians may consider use of static and dynamic (nonwalking) balance strategies when coupled with VR or augmented visual feedback to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for individuals with stroke).

Action Statement Profile

Aggregate evidence quality: Level 1. (A) Based on 6 level 1 and 5 level 2 RCTs (combined n = 240), exercises focused on trunk stabilization or weight-shifting activities in sitting or standing demonstrate limited gains in walking speed and distance as compared with alterative rehabilitation strategies. (B) Based on 4 level 1 RCTs (combined n = 175) examining the efficacy of postural training with whole-body or local vibration, limited gains in speed and distance were observed as compared with similar exercises without vibration or other interventions. (C) Based on 5 of 9 RCTs (6 level 1 and 3 level 2; combined n = 207), clinicians may consider the use of augmented visual feedback coupled with static or dynamic (nonwalking) balance to improve walking function.

Benefits: There appears to be little benefit of providing static or dynamic (nonwalking) balance training without augmented or virtual reality on walking speed and distance as compared with alternative interventions. Balance training in combination with augmented or virtual reality may be of benefit to improve walking outcomes as compared with no intervention or as compared with training interventions without altered or augmented visual input.

Risks, harm, and costs: Increased costs and time spent may be associated with travel to attend balance-training sessions. Training in a virtual environment or with whole-body or local vibration requires additional equipment that may not be readily available to clinicians and/or may be expensive. Training activities without altered or augmented input may provide limited benefit in consideration of the costs, travel, and time associated with these strategies.

Benefit-harm assessment: **Preponderance** of risks, harm, and costs.

Value judgment: There are limited details regarding the relative intensity of the postural perturbation strategies described in all studies. The findings suggest that strategies that encourage volitional participation through augmented feedback may have potential for positive benefits on walking function.

Intentional vagueness: The available literature does not provide sufficient evidence regarding the frequency, intensity, and duration sufficient for prescription recommendations as detailed in the action statement.

Role of patient preferences: Patients may be less willing to participate in interventions that demonstrate limited benefit over alternative interventions. Patients may prefer to utilize feedback systems during balance training to increase engagement, although others may be hesitant to use advanced technology.

Exclusions: There are no documented exclusions for potential participants. Studies with VR often used custom-based systems and use of commercially available systems may not result in similar outcomes.

Quality improvement: Patients may improve walking with static or dynamic (nonwalking) balance training, although only when combined with VR as available. If specific equipment is not available, therapists should minimize static balance practice and provide alternative, recommended interventions.

Implementation and audit: The costs and training associated with clinical implementation of VR systems will need to be justified, although selected systems may be utilized during other walking tasks to enhance usability during various interventions.

Supporting Evidence and Clinical Implementation

The ability to maintain postural stability and balance during static or dynamic (nonwalking) tasks is a major impairment following neurological injury and is strongly associated with fall risk ad reduced participation.[199,200] Indeed, impaired balance is a primary predictor of locomotor function in the chronic phases following CNS injury,[65,67] and training activities directed toward improving postural control are a major focus of traditional rehabilitation strategies. Specific interventions have included focus on challenging trunk stability during sitting exercises and progression to standing balance activities, focus on symmetrical weight bearing using various weight-shifting techniques, postural perturbations such as reaching outside of the base of support, standing with altered bases of support (ie, feet together or tandem), or sitting or standing on uneven surfaces. Additional sensory inputs may be provided, including altered visual input to increased visual feedback via VR, or provision of specific physical inputs such as vibratory stimuli.

(A) Appendix Table 6A-C details the evidence describing the effectiveness of balance training interventions. Appendix 6A shows 11 studies that evaluated the effects of sitting or standing balance (ie, postural) training on walking function in individuals greater than 6 months following stroke, iSCI, and TBI. Three studies evaluated the effects of stabilizing the trunk during sitting or standing activities, revealing no significant improvements in walking function as compared with traditional sitting or standing exercises that did not challenge trunk stability. Two level 2 studies evaluated the benefits of sitting balance training on postural stability on sitting and standing assessments in addition to walking speed poststroke. In 20 individuals poststroke, Dean and Shepherd[115] examined the effects of standardized seated training program that encouraged patients to grasp objects greater than arm's length in various directions as compared with reaching for objects within arm's length. Increased effort was required in the experimental training program by altering seat height or distance reached. In the comparison intervention, participants reached for objects while the difficulty of simultaneous cognitive tasks was increased. Both groups practiced a similar number of reaching tasks, with greater improvements in reaching distances and alteration in ground reaction forces in the paretic limbs during sitting in the experimental group. However, there were no reported differences in changes in 10MWT posttraining between groups. In the study by Kilinc et al,[116] postural and trunk exercises performed using Bobath (ie, neurodevelopment treatment) techniques were compared with generic exercises of the limbs and trunk in 22 individuals with chronic stroke. Measures of trunk impairments, functional reach, and Berg Balance Scale revealed slightly higher increases following Bobath training, with no observed difference in changes in 10MWT between the 2 groups. In another level 2 study, Chun et al[117] evaluated the effects of lumbar stabilization training as compared with postural standing training in individuals with chronic stroke. Over 7 weeks of training, participants with chronic stroke randomized to the experimental group received 30 minutes of trunk stabilization activities using a specific training device (Spine Balance 3D) that stabilized the limbs and pelvis during standing. Participants were tilted up to 30° from vertical in multiple directions in an effort to increase trunk muscle activation. This training was compared with postural stability training using the Biodex Balance Master to maintain symmetrical weight bearing. Changes in 10MWT were not significantly different between groups, with no reported differences in Berg Balance Scale, Functional Reach Test, muscle strength, or Timed Up and Go.

The effects of weight shifting and symmetrical weight bearing also revealed limited benefit as compared with other exercise strategies with limited attention toward weight-bearing symmetry. In 1 level 1 and 3 level 2 articles recruiting participants with chronic stroke, locomotor function observed following various weight-shifting strategies, including use of single-limb stance training, use of a heel lift on the nonparetic limb, and tai chi exercise, was not improved consistently as compared with other therapeutic strategies. Aruin et al[119] and Sheikh et al[120] both investigated the effects of compelled weight shifting using a shoe-insert on the nonparetic limb in participants with chronic stroke. In the study by Aruin et al,[119] 18 participants completed 6 training sessions over 6 weeks, with exercise strategies that included balance activities, strengthening with elastic resistance, recumbent stepping, and selected walking exercises. The experimental group performed these activities wearing a shoe lift, while the control group did not. Posttraining assessments revealed no significant differences in changes in 10MWT, with small improvements in standing weight bearing on the paretic limb in the experimental group. Similarly, Sheikh et al[120] trained 28 individuals poststroke to perform standing, balance, and walking activities during up to 36 sessions over 6 weeks, with the experimental group using a shoe lift. Weight symmetry during standing improved to a greater extent in the experimental versus control group, with no changes in gait speed or any gait symmetry measures. In another study by You and colleagues,[121] use of a unilateral device to maintain a flexed hip/knee posture during gait and balance activities was performed over 8 weeks for 1.5 hours per day. Changes in locomotor and other clinical outcomes were compared with those observed following similar training strategies, except without the use of the device during physical therapy (PT) activities. In 27 individuals poststroke, there were no significant differences in the changes in 10MWT between the groups. In a separate study, Kim et al 2015[118] compared the effects of additional 30 minutes per session of tai chi exercises with general PT as compared with general PT activities. Both groups attended training sessions twice a week for up to 6 weeks. Tai chi training was performed using an experienced instructor guiding participants through 10 movements in a standing position, including weight shifting and unilateral stance activities. In 24 participants with chronic stroke, posttraining assessments revealed significant differences in 10-m walk, Timed Up and Go, and other measures of standing postural control in the experimental versus control group. Notably, these significant findings were revealed without an equivalent amount of therapy, whereas other studies focusing on weight shifting and symmetry with similar total duration of therapies between experimental and control group revealed no benefit.

The effects of altered visual and somatosensory input during postural stability exercises were assessed in 3 level 1 and 1 level 2 studies, revealing no additional gains in walking function as compared with similar exercises without altered sensory feedback. In the study by Bonan et al,[124] 20 individuals with chronic stroke were randomized to receive twenty 1-hour sessions of specific balance exercises over 4 weeks, with vision occluded with a mask as compared with no visual occlusion. Both groups received 5 minutes of stretching, with 30 minutes of supine, sitting, kneeling, or standing exercises challenging postural stability, as well as 20 minutes of postural stability during walking on a treadmill or over an unstable surface overground, or during stationary cycling. Greater improvements in selected measures of standing balance were observed in the experimental versus control group, although there were no differences in changes in gait speed between groups. Similarly, Bayouk et al[123] investigated the effects of balance exercises performed in 16 individuals with chronic stroke with and without altered sensory feedback. During 16 1-hour therapy sessions over 8 weeks, participants with stroke practiced dynamic balance exercises (sitting, standing, transfers, stepping in place or for limited distance walking in difference directions), with the experimental group performing half of the exercises with vision occluded or over an unstable surface (foam mat). The control group performed similar activities without changing visual or somatosensory feedback during training. At posttraining, changes in the 10MWT were not different between groups, with additional outcomes of center of pressure sway revealing small improvements in the experimental group. Furthermore, Kim et al[98] evaluated the effects of 40 sessions over 8 weeks of conventional therapy with 30 minutes of additional standing balance training, as compared with 40 sessions over 8 weeks of ankle strengthening exercise plus conventional therapy. Participants in the experimental group ($n = 13$) performed balance training on the Biodex Balance System, with 9 different conditions of altered visual and audio input with perturbations of the standing platform. In the control group ($n = 14$), strength training was performed with the dorsi-and plantar flexors for 30 minutes in isometric, isotonic, or open/closed kinetic chain exercises at 70% of 1RM, although details of the number of repetitions and sets were not provided. Changes in 10MWT and the Functional Reach test were greater following balance versus strength training. The combined data suggest limited benefit of balance training in sitting or standing as compared with more conventional strategies. Finally, Bang et al[122] evaluated the effects of an additional 30 minutes of standing balance activities performed on unstable (ie, compliant foam) surfaces immediately following 30 minutes of treadmill training for 20 sessions over 4 weeks as compared with only 30-minute sessions of treadmill training. In 12 participants poststroke, the average changes with the additional training in the experimental versus control groups in the 6MWT (54 vs 48 m, respectively) were considered significantly different between groups, with no differences in 10MWT.

(B) Postural/balance training has also been provided with augmented tactile and proprioceptive input using local or whole-body vibration (WBV) techniques. In these studies, participants are instructed to stand on a level platform that provides a vibratory stimulus to the feet. Conversely, other devices may provide a specific (ie, focal) vibration to specific lower extremity musculature during a postural task. The goals of these training paradigms are to augment the sensory experience for the user to facilitate augmented postural stability, potentially by increasing Ia afferent excitability to spinal motoneurons.

Appendix Table 6B shows 4 level 1 studies that suggest limited improvements in locomotor performance in participants in the chronic stages following stroke, iSCI, and TBI with vibratory stimuli during postural tasks or various exercises. Three studies provided WBV during standing in participants with chronic stroke revealing no specific improvement as compared with other exercise activities. For example, Brogardh and colleagues[125] provided supervised WBV training over 12 weeks using larger amplitude vibration, with comparisons to a placebo group receiving vibratory stimuli at smaller amplitudes. Improvements in gait speed and balance were negligible and not different between groups. In the studies by Lau et al[126] (n = 82) and Liao et al[128] (n = 84), WBV provided during dynamic leg exercises performed over 24 to 30 sessions over 2 to 3 months at specific higher frequencies and amplitudes did not improve walking function to a greater extent than lower intensity WBV or no WBV provided during leg exercises. In a fourth study, Lee et al[127] provided postural stability training with additional impairment-based exercises for thirty 30-minute sessions over 6 weeks with local vibration applied over the triceps surae and tibialis anterior tendons. Changes in outcomes were compared with a control group that practiced similar exercises with a sham vibratory stimulus, with primary results suggesting a greater improvement in gait speed in the experimental group. The collective results suggest limited and inconsistent gains in walking function by applying vibratory stimuli with postural training and other exercises.

(C) In an effort to further augment the efficacy of postural training, selected studies have incorporated augmented visual feedback, or virtual environments, that enhances the interaction between the user and the simulated environment to increase engagement and provide feedback of performance. Appendix Table 6C shows 6 level 1 and 3 level 2 studies that suggest that the effects of augmented or virtual reality during lying, sitting, or dynamic standing (nonwalking) tasks were evaluated as compared with other therapeutic activities without VR or no therapy. In 3 level 1 and 1 level 2 studies, the effect of additional virtual or augmented reality exercise in addition to regular PT was compared with regular PT alone. In the studies by both Lee et al[130] and Park et al,[131] participants in the experimental group received twelve 30-minute sessions of postural VR training over 4 weeks in addition to 30-minute sessions of conventional PT 5 days per week over a similar training period. The control groups received only the 30-minute conventional therapy sessions. Computer-based feedback of movement was provided during supine, sitting, and standing exercises during experimental training, whereas conventional therapy in both groups focused on static and dynamic balance training and gait training. Significantly greater gains in walking speed were observed in only 1 of these studies,[130] with additional improvements in selective measures of balance. In addition, the study by Yom et al[132] performed balance activities with augmented visual input for 30 minutes a day, 5 times a week for 4 to 6 weeks in addition to conventional physical therapy In this study,[132] the experimental intervention followed conventional physical therapy delivered 30 minutes per session, 10 sessions per week over a 6-week period. The control group received conventional therapy at a similar frequency, and participants watched a documentary instead of practicing physical tasks.[132] In both studies, participants in the conventional rehabilitation plus balance exercises showed significantly greater improvements in walking speed than those who received conventional rehabilitation alone. Notably, participants in the experimental group received 150 additional minutes per week of motor training, which may contribute to the observed results. Also, in a study by Kim and colleagues,[129] both experimental and control groups received sixteen 40-minute sessions over 4 weeks consisting of specific neurofacilitation techniques focused on static and dynamic standing training to improve weight shifting. The experimental group received an additional 30-minute session of VR postural training with a head mounted VR system such that participants could practice various dynamic standing tasks. The results indicate a significantly greater improvement in 10MWT as well as gains in specific measures of balance following the experimental versus control interventions.

The effects of balance training coupled with augmented or VR therapy as compared with another training paradigm of equivalent duration were also assessed in 2 level 1 studies and 2 level 2 studies. In the studies by both Chung et al[133] and Llorens et al,[135] individuals with chronic stroke were randomized to either balance training combined with augmented visual feedback (VR) using custom-made head-mounted VR systems or balance training without augmented visual input. Llorens and colleagues[135] provided training for twenty 1-hour sessions over 4 weeks, during which participants randomized to the experimental group were provided 30 minutes of conventional training of standing exercises, including weight shifting, reaching tasks, and stepping in place, with some additional walking conditions. An additional 30 minutes was dedicated to performance of stepping tasks during standing, during which participants were challenged to place 1 foot toward a target while maintaining balance. The comparison group received 1 hour of conventional therapy. In the study by Chung et al,[133] participants were provided eighteen 30-minute sessions over 6 weeks, with the experimental group performing supine or sitting postural exercises focused on core stabilization with head-mounted VR systems to provide feedback of movement kinematics. In contrast, the control group performed similar balance activities for the same duration and number of sessions. Both studies revealed greater improvements in the 10MWT following experimental versus control training, with additional gains in selected balance measures.

In contrast, 2 studies by Song and Park[104] and Gil-Gomez et al[134] found no greater improvements in locomotor function following augmented visual input during balance training as compared with training without VR or conventional strategies. Gil-Gomez et al[134] reported the effects of dynamic balance training on 17 participants with acquired brain injury (ie, stroke and TBI) using the Nintendo Wii over twenty 1-hour sessions. Using 3 different custom-made gaming programs challenging postural stability during standing tasks, the authors found no significant improvement in the 10MWT as compared with an equivalent number of sessions focused on balance training. Similarly, Song and Park[104] compared the effects of VR balance training with lower extremity ergometry training in 40 participants with chronic stroke. Individuals in the experimental group performed training using the Xbox Kinect for forty 30-minute sessions over 8 weeks, with focusing on gaming activities that focused on dynamic balance and weight shifting. Participants in the control group performed MOTOmed lower extremity ergometer training over forty 30-minute sessions targeting up to 40% of HR reserve. The authors report a difference in changes in 10MWT between groups, although both groups demonstrated a decrease in gait speed, with results of other clinical balance tests demonstrating little difference.

Finally, Fritz and colleagues[136] studied a cohort of 30 participants with chronic stroke who were randomized to receive either balance training using a commercial gaming systems (Nintendo Wii and PS) for twenty 50-minute sessions performed over 5 weeks or no interventions. Gaming sessions were not standardized and the users selected specific games that incorporated physical activities with suggestions provided by assistants. Visual and auditory cues were provided by the gaming systems, with assistants present to optimize posture during task performance. Although improvements in both walking speed (3-m walk test) and endurance (6MWT) were observed in both groups, differences between groups were not significant.

In summary, the studies detailing the effects of sitting and standing balance with altered feedback received 4 total points out of 22 possible points (11 articles considered), resulting in 18% of available points. Balance training with additional vibration received 2 of 8 possible points (25%), and balance training with augmented visual feedback/VR received 6 of 18 possible points (33%). Potential limitations of most studies include lack of details of the total amount of practice or intensities of practiced tasks to determine their potential influence on outcomes. Additional limitations include the lack of consistency of VR systems and differences between studies may account for inconsistent results.

Research recommendation 6: Further studies are required to verify the results of selected positive studies incorporating VR systems during balance training, including potential comparative efficacy studies utilizing different gaming systems, and further details on amounts, types, and intensities of practice provided.

Action Statement 7: BODY WEIGHT SUPPORTED TREADMILL TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and limited evidence in iSCI and TBI, clinicians should not perform body weight–supported treadmill training (BWSTT) for improving walking speed and timed distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for stroke).

Action Statement Profile

Aggregate evidence quality: Level 1. Based on 9 RCTs (6 level 1, 3 level 2; combined n = 275), there is limited benefit of providing BWSTT to improve walking speed and timed distance as compared with alternative interventions in ambulatory individuals with chronic stroke, iSCI, and TBI.

Benefits: There appears to be little benefit of BWSTT on walking speed and distance as compared with overground walking training or other interventions in ambulatory individuals with chronic stroke, iSCI, and TBI.

Risks, harm, and costs: Increased costs and time may be associated with travel to attend BWSTT interventions. Additional costs are associated with the expense of these devices and the personnel utilized to deliver this training to facilitate kinematic trajectories as indicated in selected studies.

Benefit-harm assessment: Preponderance of risks, harm, and costs.

Value judgment: All studies included significant therapist assistance in addition to the BWS, which may reduce the intensity of walking training. Use of BWSTT without significant additional therapist support may yield different results. Most all participants included in these studies were also able to ambulate overground without the use of BWS. Different results may occur in those who are nonambulatory or unable to ambulate without BWS.

Intentional vagueness: Use of substantial BWS and physical assistance may be contributing factors that resulted in negligible improvements as compared with other strategies.

Role of patient preferences: Patients may be less willing to participate in interventions that demonstrated limited benefit over alternative interventions.

Exclusions: Given the use of primary outcomes of walking speed or timed distance, most studies included participants who were able to ambulate with or without BWS or physical assistance. This recommendation may not apply to nonambulatory individuals or those who require BWS or assistance to ambulate.

Quality improvement: Therapists may consider reducing the amount of physical or mechanical assistance if patients can independently perform stepping activities. Increased volitional effort without assistance will increase the neuromuscular and cardiopulmonary demands of stepping training, and documentation of intensity (HR, RPE) may therefore be warranted.

Implementation and audit: Use of BWS and substantial physical assistance to ambulate may not be necessary in those who are ambulatory. Rather, clinicians may be able to gauge stepping independence with the harness to ensure safety during walking practice. Substantial support or assistance may be required in nonambulatory individuals to allow stepping.

Supporting Evidence and Clinical Implementation

Following stroke, iSCI, and TBI, the ability to bear full body weight during walking is often impaired.[201-204] This impairment often limits walking training and has led to the development of harness systems that can be adjusted to support a percentage of full body weight during walking.[35,204,205] These systems are often coupled with a motorized treadmill to allow for repetitive stepping practice and have been used in persons with iSCI, TBI, and stroke. In addition, therapists often provide physical assistance to allow continuous stepping and often attempt to facilitate "normal" stepping patterns during walking exercise.[206-208]

Strong evidence indicates that BWSTT compared with overground walking training does not result in greater walking speed or distance in patients greater than 6 months following stroke, iSCI, and TBI (see Appendix Table 7). Three level 1 and 2 level 2 articles showed no benefit of BWSTT compared with overground walking training,[137-140,148] and 1 study showed greater benefit of overground walking training.[36] Studies varied in the duration of individual training sessions, total duration of the intervention, and the intensity of training.

In a study of participants with iSCI, those who performed BWSTT walked 3× per week for 60 minutes per session for 13 weeks with 30% BWS at a self-selected pace with assistance to advance the leg when needed.[137] This training was compared with a conventional PT group and a group doing overground walking with BWS of same duration, speed, and assistance. Average HR over the session was monitored although intensity was not controlled and statistical differences between groups were not reported, though qualitatively, the overground group had the highest average HR during training. No differences in walking speed were found between groups.[137]

In a study of participants with TBI,[138] those in the BWSTT trained 2× per week for 14 weeks, 15 minutes per session and were compared with a group doing standard overground walking training of the same duration of treatment. Both groups also received 30 minutes of exercise tailored to their individual needs. Body weight support was started at 30% and was reduced by 10% when the subject could achieve 10 consecutive heel strikes during walking and physical assistance was provided by 1 to 3 therapists to facilitate normal kinematics and weight shifting. Speed of the treadmill was increased as subject tolerated. Intensity of training was not reported. No differences were found between groups for walking speed or 6MWT.

In another study,[36] participants with chronic stroke trained 30 minutes, 5× per week for 2 weeks in either a BWSTT or overground walking group. In the BWSTT group, BWS began at 30% and reduced to 15% when participants could walk at 2.0 mph and did not require assistance from the therapist. During overground walking, participants were encouraged to walk as fast as possible but not to exceed the moderate-intensity level. No differences were observed in 6MWT between groups, although greater gains in walking speed favored the overground group.

In a similar study, participants with chronic stroke trained daily for 25 min/d, 4 d/wk for 4 weeks performing either BWSTT or overground walking training.[140] Two therapists assisted walking and BWS started at 30% and was decreased each week by 10% BWS. Walking speeds started at 0.044 m/s and increased by 0.044 m/s each day as tolerated, although training intensity was not reported. No differences in walking speed were found between groups.

In 1 other study,[139] participants with chronic stroke trained for 3 h/d for 10 days, with 1 hour directed toward balance training, 1 hour toward strength training, range of motion and coordination, and the final hour either BWSTT or overground walking training, depending on group assignment. In the BWSTT group, BWS ranged from 8% to 50% and manual assistance was provided if the subject could not generate normal kinematics. Intensity and speed of training was not detailed other than that goals of training were to maximize speed and minimize BWS. No differences were found between groups for walking speed or 6MWT.

One level 2 study compared BWSTT with overground walking in persons with iSCI.[141] Participants in both groups participated in 30 semiweekly sessions lasting 30 minutes each consisting of passive stretching and joint mobilization and either BWSTT or overground walking training, depending on group assignment. Body weight support began at 40% and was reduced by 10% every 10 sessions. Participants walked at their self-selected speed while assisted by 2 therapists. Between-group comparisons were not performed, although there were improvements in walking speed following BWSTT but not overground training.

In contrast to the results comparing BWSTT with overground walking, there is some evidence that BWSTT may improve locomotor outcomes when added to conventional physical therapy or compared with no intervention in persons in the chronic stages following stroke, iSCI, and TBI. Three level 1 studies compared BWSTT 2 to 5× per week for 4 weeks to (1) proprioceptive neuromuscular facilitation,[142], (2) no intervention,[144] or (3) stretching, muscle strengthening, balance, and overground walking training.[143] Of note, Yen et al[143] provided BWSTT *in addition* to the other exercise and participants therefore received an additional 30 minutes 3× per week of BWSTT. Participants in the BWSTT group trained at a variety of speeds, including as fast as possible,[144] their comfortable speed[142] or according to subject ability.[143] Participants were provided 20% to 40% BWS, which was either maintained throughout training or reduced when the subject could support body weight on the paretic limb without assistance from therapist or greater than 15° knee flexion during stance.[142,143] In 2 studies, participants were assisted by 1 to 2 therapists to help achieve normal kinematics.[142,143] In the third study, there was no indication that assistance was provided by therapists during walking.[144] Intensity of training was not reported in any of the studies. Two of the 3 studies found greater improvements in walking speed in the BWSTT group[143,144] and 1 study found no differences between groups.[142] Importantly, participants in the study by Yen et al[143] received BWSTT in addition to other therapy, while outcomes from the study by Takao et al[144] compared BWSTT with no intervention. These differences in protocols may account for the differences in outcomes.

Finally, 1 level 1 study by Sullivan and colleagues[32] compared BWSTT at faster speeds (2.0 mph) with slower (0.5 mph) or variable speeds (0.5-2.0 mph). Participants were provided training for 12 sessions (20 minutes per session) over 4 to 5 weeks. Up to 40% BWS was provided and reduced as long as subjects could maintain speed and proper limb kinematics. Participants were allowed to rest as needed. Although all groups improved their 10MWT, there were no differences between groups. However, this article is not scored as it compares BWSTT with other BWSTT techniques (Appendix Table 7).

In summary, the studies detailing the effects of BWSTT received 2 total points out of 18 possible points (11% of 9 articles considered). Most all participants included were already able to ambulate without the use of BWS or physical assistance. This recommendation may therefore not apply to nonambulatory individuals or those who require BWS to ambulate due to impairments from the CNS injury or to other comorbid conditions.

Research recommendation 7: Further studies should evaluate the amounts and intensities of stepping activities during BWSTT to ensure volitional engagement.

Action Statement 8: ROBOTIC-ASSISTED WALKING TRAINING FOLLOWING ACUTE-ONSET CENTRAL NERVOUS SYSTEM (CNS) INJURY. Based on the preponderance of evidence for individuals poststroke and iSCI, and limited evidence in TBI, clinicians should not perform walking interventions with exoskeletal robotics on a treadmill or elliptical device to improve walking speed and distance in individuals greater than 6 months following acute-onset CNS injury as compared with alternative interventions (evidence quality: I-II; recommendation strength: strong for stroke and iSCI).

Action Statement Profile

Aggregate evidence quality: Level 1. Based on 8 level 1 and 3 level 2 RCTs (combined n = 348) comparing robotic-assisted walking training with alternative strategies. No significant differences in walking speed or distance in ambulatory individuals with chronic stroke, iSCI, and TBI were found between groups. Four additional studies (n = 69) compared swing assistance with swing resistance revealing no differences in outcomes.

Benefits: There appears to be little benefit of robotic-assisted training on walking speed and distance as compared with overground walking training or other interventions in ambulatory individuals with chronic stroke, iSCI, and TBI.

Risks, harm, and costs: Increased costs and time may be associated with travel to attend robotic-assisted training interventions. Robotic devices used to assist the limbs during stepping tasks may be expensive. Skin irritation and leg pain have occurred with robotic training.

Benefit-harm assessment: Preponderance of risks, harm, and costs.

Value judgment: Most studies included BWS in addition to robotic assistance, both of which may reduce training intensity. Use of robotic training during walking training without significant additional BWS may yield different results. All participants included in these studies were also already able to ambulate without the use of a robotic device, and results may vary in patients who are nonambulatory or unable to ambulate without the robotic device.

Intentional vagueness: The amount of robotic assistance and, if necessary, BWS may be contributing factors that resulted in little functional improvements with this training paradigm as compared with other strategies.

Role of patient preferences: Selected individuals may wish to engage with advanced technology, while others may be fearful of such technology. Patients may be less likely to participate in interventions that demonstrated limited benefit over alternative interventions.

Exclusions: Given the use of primary outcomes of walking speed or timed distance, most studies likely included only those participants who were able to ambulate without robotic assistance. This recommendation may not apply to nonambulatory individuals or those who require robotic assistance to ambulate.

Quality improvement: Therapists may consider reducing the amount of mechanical assistance if patients can independently perform stepping activities. Increased volitional effort without assistance will increase the neuromuscular and cardiopulmonary demands of stepping training, and documentation of intensity (HR, RPE) may therefore be warranted.

Implementation and audit: Patient outcome may be improved if robotic devices facilitate increased engagement or neuromuscular activity, and therapists should consider monitoring cardiovascular responses during training.

Support Evidence and Clinical Implementation

After chronic CNS injury, abnormal walking patterns are common.[188,201,209] Robotic devices have been developed to assist with labor-intensive walking training that focuses on producing more normal walking patterns after chronic CNS injury.[210-213]

Strong evidence (6 level 1 and 1 level 2 articles) indicates that walking training with robotics compared with walking training alone does not result in greater walking speed or distance in people in the chronic stages following stroke, iSCI, and TBI[37,146-150] (see Appendix Table 8). In 4 of the studies,[37,147,148,150] participants participated in walking training with the Lokomat robot and BWS of 10% to 35%, and the control group trained with BWS (10%-30%) and manual assistance from therapist during treadmill walking. In the study by Field-Fote and Roach,[148] participants were also assigned to an overground walking group or a treadmill training group with electrical stimulation. Training ranged from 12[37,150] or 18 sessions,[147] up to 60 sessions,[148] with each session between 20 and 45 minutes in duration. Training speeds also varied between studies. In the study by Esquenazi et al,[147] speed was set to the self-selected walking velocity, which was reassessed at every third training visit. In the study by Hornby et al,[37] training speed was started at 2.0 kmph and increased by 0.5 kmph every 10 minutes as tolerated until 3.0 kmph was reached. In the study by Westlake and Patten,[150] speeds were maintained below 0.69 m/s for a group stratified by slower walking speeds and above 0.83 m/s in those with faster walking speeds. Participants in the study by Field-Fote and Roach[148] were encouraged to walk as fast as possible. Significant differences in walking speed between groups were found only in the study by Hornby et al,[37] although results favored the nonrobotics group. Differences in walking distance between groups were found only in the study by Field-Foote and Roach[148] and were also in favor of the nonrobotic walking group(s).

Two additional studies evaluated the effects of walking training with robotics to walking training alone and revealed no differences in walking outcomes in people with chronic stroke.[146,149] In these studies, participants in the robotics group trained with an electromechanical gait trainer with BWS[149] or a Stride Management Assistance device that provides assistance at each hip joint during overground walking.[146] In the study by Peurala et al,[149] participants were assigned to a robotic walking training group, a robotic training and lower extremity electrical stimulation group, or an overground walking group. Walking training in each group occurred for 20 minutes in addition to regular physical therapy. Participants trained 5 times per week for 3 weeks. No differences in walking speed or distance on 6MWT were found between groups. In the study by Buesing et al,[146] participants in the nonrobotic group completed high-intensity treadmill training (75% HR_{max}) and functional mobility training. In the robotics group, participants trained at high-intensity overground (75% HR_{max}) along with functional walking training including multiple surfaces, obstacles, and stairs. Participants in both groups trained for 45 minutes per session, 3 times per week for 6 to 8 weeks. No differences in walking speed were found between groups following training.

In a final study comparing walking training with robotics to walking training alone,[145] participants were assigned to a Lokomat treadmill training group with up to 40% BWS or a treadmill training alone group without body weight support or therapist assistance. Participants in both groups trained 1 hour per session, 5 times per week for 4 weeks. In the robotic group, speeds started at 0.45 m/s and were progressed as tolerated, and BWS was reduced throughout the sessions. In the control group, speeds were increased in each 1 to 2 walking bouts as tolerated by the subject, with the goal to walk as fast as possible. Improvements in walking speed were significantly greater in the robotics group.

Strong evidence also exists (2 level 1 and 2 level 2 studies) that walking training with robotics does not result in greater walking speed or distance for people with chronic CNS injury compared with conventional physical therapy, seated robotic training, or strengthening.[99,151-153] In the study by Stein et al,[151] participants wore a powered knee orthosis and participated in walking and functional mobility training for approximately 50 minutes per session, 3 times per week for 6 weeks. Participants in the control group participated in the same amount of group therapy focused on stretching and low-intensity walking. There were no differences found between groups in walking speed or distance on the 6MWT.[151]

In the study by Labruyère and van Hedel,[99] participants with SCI either trained on the Lokomat or completed lower extremity strength training for 45 minutes, 4× per week for 4 weeks and then crossed over to the alternate intervention. In the Lokomat group, BWS started at 30% and decreased as tolerated and speeds started at 1 to 2 km/h and increased as tolerated. Fast walking speed as measured by the 10MWT increased more in the strengthening group, while there was no difference in self-selected walking speed between groups.

In the study by Ucar and colleagues,[152] participants with chronic stroke were assigned to treadmill training with the Lokomat or to a conventional physical therapy group, consisting of active and passive range of motion, active-assistive exercises, strengthening of the paretic leg, and balance training. Participants in both groups trained in 30-minute sessions, 5 sessions per week for 2 weeks. In the Lokomat group, speeds were around 1.5 kmph and BWS was about 50%. If participants could increase speed beyond 1.5 kmph with full body weight, then assistance from the Lokomat was reduced. In this study, the change in gait speed from pre- to posttraining was not compared across groups, but there was a significant difference in gait speed between the 2 groups at the posttraining time point, favoring the robotics group.

Several studies have examined differences in locomotor outcomes when swing resistance versus swing assistance was provided by a robotic device during walking training in people with chronic CNS injury.[154-157] Two studies examined persons with chronic spinal cord injury[154,156] and 1 in individuals poststroke,[155] training 3 times per week, 12 to 36 sessions with either external swing assistance or resistance provided by either a cable-driven robotic device or the Lokomat, respectively. In all 3 studies, while walking speed and distance on the 6MWT improved in both groups, no differences in improvements between groups were found. In a separate study using a crossover design,[157] participants with iSCI were randomly assigned to walking training with first either swing resistance or swing assistance provided by a cable-driven robotic device for 4 weeks and then crossed over to the opposite group for another 4 weeks of training. Walking speed and distance increased during both forms of training, with no difference between groups. These studies were not scored and did not contribute to the recommendation because they compared different forms of robotic-assisted walking training without indication of differences in other FITT parameters.

In summary, the studies detailing the effects of robotic-assisted walking training received 4 total points out of 22 possible points (18% of 11 articles considered). Importantly, all participants included in these studies were likely able to ambulate without the use of robotic assistance, given the use of walking speed and timed distance as outcome measures. This recommendation may therefore not apply to nonambulatory individuals or those who require robotic assistance to ambulate due to significant impairments or to other comorbid conditions. Furthermore, most studies did not indicate targeted or achieved training intensities, which have been postulated to account for some of the inconsistent and negative findings.[214]

Research recommendation 8: Further studies should evaluate the amounts and intensities of stepping activities during experimental robotic therapies to ensure patient's effort and volitional engagement.

Additional Studies

Other studies fulfilled all inclusion criteria and were appraised, although the variations in the types of interventions evaluated were substantial, and specific interventions did not meet the minimal number of research studies (ie, n = 4) for inclusion in this CPG. Studies detailing the efficacy of nonwalking interventions on walking speed and distance included evaluation of the effects of action observation/mental practice[215-217]; vibration on the lower leg in supine positions[218]; active and passive range of motion of impaired ankle[219]; device-assisted, seated, bilateral leg movements[220]; or ankle exercises coupled with visual feedback[221,222] or ankle exercise with mirror feedback.[223]

Additional studies that focused on walking training included 3 studies that used rhythmic auditory stimulation during walking[224-226]; 2 that used community-based ambulation training[41,227]; and studies that incorporated daily stepping feedback with treadmill walking,[228] inclined,[229] turning,[230] obstacle crossing,[231] and combined electrical stimulation with fast and slow treadmill walking.[232] Other studies utilized assisted arm swing with treadmill walking[233]; incorporated dual task performance[234]; and compared standard treadmill training without BWS to overground training,[225,235] and 2 studies evaluated treadmill training with postural corrections[236] or provided with feedback of spatiotemporal gait patterns.[237] Many of these studies demonstrated positive findings compared with the control interventions, and future revisions of this CPG may incorporate these findings given sufficient evidence.

DISCUSSION

The present CPG summarizes the relative efficacy of interventions to improve walking speed and timed distance in individuals at least 6 months following stroke, iSCI, or TBI, with attention toward the training parameters that can influence motor recovery. Recommended interventions (Table 5) that should be performed include gait training at higher intensities or combined with augmented visual feedback (ie, VR). Strategies with inconsistent evidence of efficacy include strength training, lower extremity cycling, circuit training, and standing balance exercises with augmented (VR) feedback. Strategies that are not recommended for ambulatory individuals greater than 6 months following stroke, iSCI, and TBI included sitting and standing balance training without augmented feedback, robotic-assisted walking training, and BWSTT. These recommendations were developed using specific inclusion criteria, including the patient populations described, research design considerations, and outcome measures utilized, as described previously.

Influence of Training Parameters on Locomotor Performance

A goal of this CPG was to delineate the potential contributions of the specificity, intensity, and amount of exercise provided during interventions designed to improve walking function. The cumulative evidence suggests all 3 play a role in the efficacy of rehabilitation strategies, although no single training parameter was sufficient to elicit positive outcomes.

Specifically, the amount of task-specific practice was considered an important variable, and the recommended interventions, including high-intensity stepping training and VR-enhanced walking, both provide focused stepping practice. Importantly, such practice occurred over extended durations (1-6 months) at approximately 2 to 3× per week for 1- to 1.5-hour sessions, suggesting that large amount of stepping practice was provided. A few of the studies included in this guideline measured stepping amounts during treatment sessions, indicating up to 4000 steps per session depending on the protocol utilized,[24,79,82] which represents greater daily stepping practice than patients with neurological typically achieve.[65,66] Unfortunately, other studies did not estimate total stepping activity within studies, and future studies utilizing devices to estimate the amount of stepping activity may better understand the contribution of this training parameter to changes in functional performance.

Importantly, however, BWSTT and robotic-assisted walking also provided large amounts of stepping activity, although these strategies were not recommended. A key difference between these interventions may be the intensity

TABLE 5. Final Recommendations for Clinical Practice Guideline on Locomotor Function

RECOMMENDATIONS	INTERVENTION STRATEGIES
Interventions *should be performed*	Aerobic (moderate to high) intensity walking training (intensities > 60% HR reserve or 70% HR_{max}) VR-coupled treadmill training
Interventions *may be considered*	Strength training of multiple sets and repetitions at >70% 1RM Circuit or combined training Cycling training (particularly at higher intensities) VR-coupled standing balance training
Interventions *should not be performed*	Sitting and standing balance without augmented visual input Robotic-assisted walking training BWSTT with physical therapist assistance

Abbreviations: BWSTT, body weight–supported treadmill training; HR, heart rate; 1RM, one repetition maximum; VR, virtual reality.

of practice or volitional engagement during exercises. Greater neuromuscular activity is certainly required during higher-intensity locomotor interventions to achieve the desired HR ranges. Furthermore, VR-guided activities[175] may provide greater volitional engagement with visual feedback or incorporation of salient or goal-directed tasks,[176,177] which could increase neuromuscular and cardiac demands, although measures of intensity are not provided. Conversely, cardiac demands during treadmill training with BWS and manual assistance or robotic-assisted training may be limited,[214,238] particularly if these techniques provide substantial physical guidance.[239,240] Future studies may wish to monitor cardiovascular stress during these or other interventions, even if not an explicit goal of the study, as the contributions of both amount and intensity of stepping practice may be key training parameters underlying the outcomes achieved.

Although specific walking training paradigms were recommended, other interventions that did not involve substantial amounts of stepping practice demonstrated inconsistent findings. For example, most studies evaluating the effects of circuit or combined exercise training, cycling training, or strength training were provided at relatively high intensities (eg, % maximum HR or %1RM) but did not demonstrate consistent walking improvements. Balance training with additional visual feedback also demonstrated inconsistent benefits, whereas seated and standing balance training without feedback resulted in negligible improvements above alternative strategies. The cumulative data suggest that strategies that provide large amounts of task-specific (ie, walking) practice, specifically at higher cardiovascular intensities or with increased engagement/saliency, can improve walking speed and timed distance, while nonspecific and reduced intensity interventions result in inconsistent or negligible gains in locomotor function.

Finally, the results from the VR studies were not readily anticipated, given the lack of monitoring of cardiovascular intensities during stepping tasks. However, the findings may reveal a potential contribution of the level of specificity of task practice and suggest that factors such as engagement or provision of salient tasks may further enhance the training benefits. With further applied and clinical research in the field of locomotor rehabilitation, the potential contributions of providing salient, engaging tasks should be further delineated to assist with development of more effective training protocols and clinical implementation.

Clinical Implications

These recommendations were developed in an effort to educate clinicians and facilitate clinical adoption of evidence-based strategies that can maximize walking function following acute-onset neurological injury. An important consideration regarding implementation efforts is the selection of studies using specific inclusion criteria and outcome measures. Specifically, research articles were incorporated only if participants were in the chronic stages postinjury (>6 months), and primary outcomes were walking speed or timed distance. Although these criteria were utilized to minimize the variation of natural recovery[53] or use of subjective outcomes (eg, independence in mobility), many individuals receive rehabilitation services early following injury, during which the extent of disability is more substantial. Given the specific studies incorporated in this guideline, the action statements do not directly translate to individuals early postinjury who are nonambulatory.

Given these limitations, the term "evidence-informed practice" has been utilized to facilitate application of research findings into clinical practice while incorporating the notion that specific patient presentations or contexts may differ from the research used to formulate recommendations.[241] In attempts to implement various strategies using the concept of evidence-informed practice, the general training parameters that influence outcomes may be of greater importance than the specific details of any individual training strategies.

More directly, available literature suggests that the current recommendations may extrapolate to individuals with subacute injury, consistent with the training parameters that influence responsiveness to exercise (ie, specificity, amount, and intensity). Previous and recent studies in ambulatory participants with subacute stroke suggest greater walking gains following higher-intensity stepping activities as compared with lower-intensity walking[33,38] or more conventional interventions.[242] Conversely, providing stepping training without attempts to achieve higher intensity in subacute stroke can result in less optimal outcomes, as observed with robotic-assisted training[38] and BWSTT with manual assistance.[29,243] When evaluating nonspecific (ie, nonwalking) interventions, the use of strength training[244] or balance training,[245,246] even with additional biofeedback, can also result in inconsistent improvements as compared with conventional strategies.

In evaluating data in nonambulatory patient populations, greater attention to these key training parameters may be warranted. For example, studies comparing the efficacy of BWSTT to treadmill stepping without BWS[35] or to overground walking[247,248] demonstrate significantly greater gains in locomotor independence and function in those who were nonambulatory or walked less than 0.2 m/s.[249] Although these studies contrast with current recommendations, BWSTT may have allowed greater amounts of stepping practice in more dependent participants than could be achieved with conventional methods. Similarly, gains in individuals who require significant physical assistance may also be observed with robotic-assisted walking if greater amounts of practice could be provided than without such assistance.[39] Although these strategies may be helpful following subacute CNS injury, clinicians should continue to utilize the training variables (eg, intensity, saliency, and amount of practice) that appear to influence walking outcomes. More directly, the effects of training using BWSTT and robotic-assisted training could be enhanced with greater cardiovascular and neuromuscular intensity or with provision of augmented feedback. As such, clinicians are encouraged to monitor HRs or perceived exertion during training sessions to ensure appropriate intensities and volitional engagement. Although discussion of all pertinent research in nonambulatory participants with subacute injury is beyond the scope of this CPG, it is imperative that development of additional guidelines bridges the current gaps in knowledge related to the efficacy of interventions in subacute populations.

Implementation of Recommendations

The implementation of evidence-based interventions in the field of rehabilitation has been a challenge and the development of CPGs presents a potential resource for clinicians as they attempt to integrate available research into their practice patterns. For the current CPG, the discrepancy between the recommended interventions (Table 5) and current practice patterns (Table 4) highlights the necessity for developing effective strategies for knowledge translation and implementation. To assist with these endeavors, the ANPT has commissioned a knowledge translation task force whose primary goal is to develop tools and processes that may facilitate implementation of the primary recommendations. The members of the team were selected to represent a broad range of stakeholders and the task force includes members with expertise in implementation and knowledge translation. The materials provided in this section are suggestions that represent the first step in a more detailed and thorough process.

Facilitators and barriers to application: Specific factors that can positively influence adoption of CPGs (facilitators) or impede their implementation (barriers) are multifactorial and often context dependent. We attempt to identify selected facilitators and barriers that may affect the extent to which these recommendations are utilized in standard clinical practice.

To begin, the survey completed by members of the ANPT (Table 4) helped identify treatment strategies often used to improve walking outcomes in the patient populations addressed. Preferred practice patterns in line with the recommendations are considered facilitators, including overground walking training (91% of respondents indicated top 3 interventions chosen) and treadmill training (40%). Specific barriers include those strategies that are effective but not often performed, such as aerobic training (13%). Clinicians certainly have the necessary training and skills to implement and monitor aerobic training and can easily incorporate higher-intensity activities during overground or treadmill training. Use of equipment, such as those to monitor physiological (ie, cardiovascular) responses to exercise may be of value, although their cost and availability in clinics may be perceived barriers that should not be difficult to overcome. Other costlier equipment, including harness systems over a treadmill or overground to enhance safety of performing higher-intensity activities, may present as greater barriers, although new equipment funds could be directed toward those systems rather than other technology or equipment that appears to be less effective.

Additional barriers include use of treatment strategies that are less effective, including sitting and standing balance and strength training at lower intensities, which are primary strategies used to improve locomotion in 64% and 27% of questionnaire respondents. Balance training is a major component of conventional rehabilitation strategies, and instruction in balance training techniques is embedded into many neurological rehabilitation textbooks and doctoral and residency-level educational curricula as a standard method to address potential gait deficits. Unfortunately, there is very little evidence to suggest sitting and standing balance intervention can optimize walking recovery. In addition, strength training performed in the research described is typically performed at high relative intensities (>70% 1RM), whereas many strengthening exercises performed clinically may not be targeting specific levels of intensity as recommended. In either case, however, the efficacy of these interventions is not certain. Accordingly, implementation strategies could be directed toward attempts to limit these practice patterns, or de-implement lower-intensity, nonspecific interventions from clinical practice.

Resource utilization: Implications for resource utilization, primarily regarding the time and money to deliver these interventions, were also considered. For moderate- to high-intensity walking training, one of the major advantages is that it can be readily performed with or without specialized equipment, although specific harness systems and treadmills may facilitate greater use of this technique. An additional major consideration is the use of cardiovascular monitoring during higher-intensity training protocols and potentially during initial evaluations to assess latent cardiovascular risks. This includes all moderate- to high-intensity exercises, including walking training, cycling, strengthening, and circuit training, where specific cardiac demands should be monitored continuously for safety and to achieve the recommended thresholds. Tools for monitoring can include pulse oximeters or less expensive chest- or wrist-worn heart rate monitors. If more sophisticated cardiovascular monitoring is performed during exercise testing prior to training, specifically using 12-lead electrocardiographic systems during graded exercise protocols as recommended,[250] those systems are more costly and require time and expertise of other health care professionals with experience in cardiovascular risk assessments.

Another important consideration for VR walking or balance training includes the costs of the specific VR systems that can be utilized during rehabilitation. Namely, nearly all systems used in the studies included in the CPG were customized, which could limit potential opportunities for their implementation in other settings. Alternatively, we consider the use of different VR systems across studies as a potential facilitator for implementation, in that the specific system utilized may not be critically important. A hypothesis is that simply engaging the patient with visual, interactive exercise strategies may have been sufficient to elicit the changes observed. Future studies will likely help determine what activities or VR systems may best engage patients to maximize outcomes. Future studies should also consider the cost benefit of particular VR systems.

Recommendations: The following recommendations detail strategies that may be useful for clinicians when implementing the action statements in this CPG. More detailed information will be provided by the implementation team assembled by the ANPT.

- Place a copy of this CPG in an easy-to-access location in the clinic, or similar tools developed by the ANPT-designated knowledge translation team as they become available.
- Obtain and utilize equipment that will facilitate physiological monitoring of vital signs (eg, HR monitors, sphygmomanometers) to ensure safety during higher-

intensity interventions, or visual feedback (VR) systems to increase patient's engagement.

- Implement automatic prompts in electronic medical records that will facilitate obtaining orders to attempt higher-intensity training strategies and to measure and document vital signs throughout training.
- Implement audit and feedback strategies to enhance amounts and intensities of task-specific practice provided to patients with these diagnoses, with information documented in medical records and utilized by administrators to accurately assess appropriate training as recommended.
- Provide training sessions for clinicians to discuss alternatives to common rehabilitation strategies that do not demonstrate consistent effectiveness for improving locomotor function in those with chronic iSCI, TBI, and stroke (eg, sitting and standing balance training).
- Use the graded recommendations as a means to prioritize how treatment time is used placing "should" recommendations before "may" recommendations and minimizing use of "should not" recommendations.
- Establish organizational policies for new and current employees to utilize and document evidence-based practices in electronic medical records to allow evaluation for annual employee reviews.

Limitations and Future Recommendations

Recommendations for further research on specific interventions are provided later, although additional recommendations deserve specific attention. To begin, there is a stark difference in the number of studies focused on individuals with TBI and iSCI as compared with individuals with stroke. To account for this limitation, action statements provide specific information indicating which patient populations have been tested using these interventions. Greater effort should be directed toward evaluating the efficacy of different strategies for improving locomotor function in these underrepresented populations.

In addition, while the inclusion of only RCTs (ie, level 1 or 2 studies) is considered a strength of this guideline, there are nonetheless limitations of the selected literature utilized. Many studies included in this guideline recruited very small sample sizes and hence may have been underpowered to show a statistical difference in measures of walking speed or distance. Although there are a substantial number of nonrandomized and randomized studies to evaluate the effects of physical interventions on walking function, a strong recommendation for future trials is to ensure adequate numbers of patients and performance of power analysis prior to initiation of enrollment.

Another limitation of this guideline and the incorporated studies is the lack of details regarding the dosage of physical therapy interventions. Specific details regarding duration frequency and number of sessions are often provided for the experimental intervention, although details regarding actual amounts (repetitions) or cardiovascular and neuromuscular intensities are rarely reported in experimental interventions and to a lesser extent in control interventions. In selected studies, the authors would indicate an intervention consisted of specific activities, although the tasks described may be inconsistent with standard definitions utilized by other studies. Such inconsistencies remain a barrier to evaluating the relative efficacy of various strategies and future trials incorporating any rehabilitation intervention are strongly encouraged to detail critical dosage parameters of amount, type, and intensity of interventions.

An additional concern is the costs associated with specific recommendations, such as VR-guided stepping training and (to a lesser extent) balance training. These costs may be exorbitant, given that many studies used custom-made systems that may be more sophisticated (and perhaps more effective) than commercial VR products, which may be prohibitive for clinical adoption. Although the use of rehabilitation robotics has not necessarily been hampered by the cost of specific devices, the lack of sufficient data regarding the cost-effectiveness is an area of rehabilitation research to better understand the value of the interventions provided. Integrating additional cost-effectiveness analysis in further research should provide greater insight into both the efficacy and the efficiency of the rehabilitation interventions therapists provide.

Finally, the current CPG utilized only measures of gait speed and timed distance as the primary walking outcomes, in part due to their relatively consistent use to asses walking function across studies and the recent recommendations from the APTA-sponsored CPG on outcome measures.[70] However, we recognize that other walking-related outcomes may be important, including measures of dynamic stability while walking, peak walking capacity on a treadmill, or subjective and objective measures of community mobility (daily stepping). This last measure may be critical for the general health and function of participants and has been difficult to improve in many studies, even those that elicit significant improvements in walking speed and function (see, however, the studies by Moore et al[24] and Danks et al[228]). Future studies may wish to incorporate measures of community mobility to assess real-world changes in walking function.

CONCLUSIONS

The available evidence related to strategies to improve walking speed and distance in those greater than 6 months following an acute-onset neurological injury has increased dramatically in the past few decades. Discussions have moved away from training compensatory strategies with limited chances of recovery to acknowledgement that specific rehabilitation strategies may be critically important to enhance walking function. The current CPG was designed to highlight these strategies as determined by pertinent research studies developed during these past decades. As research evolves, this CPG will be updated to reflect the state of the science and may be expected to further refine clinical and research recommendations to enhance evidence-based practice.

SUMMARY OF RESEARCH RECOMMENDATIONS

Research Recommendation 1: The effects of high-intensity walking exercise are consistent, although variations in the intensity of exercise and amount of stepping practice performed warrant further consideration. Furthermore, the effects and safety of achieving higher intensities, as performed during selected studies, should be assessed.

Research Recommendation 2: Future studies should evaluate measures of total amount of training (repetitions of activity) and training intensity to determine their relative contribution to these VR-coupled walking trials. In addition, the specific VR systems used during training may differ in their ability to engage patients, and their relative efficacy should be evaluated.

Research Recommendation 3: Specific comparisons between higher-intensity (≥70% 1RM) strengthening interventions for multiple sets and repetitions against other task-specific (ie, walking interventions) activities should be performed to evaluate the relative efficacy of these strategies on both walking and strength outcomes.

Research Recommendation 4: The data regarding the efficacy of cycling exercise on walking function suggest a potential benefit if higher-intensity exercise is performed, and further studies should evaluate the efficacy of cycling, particularly as compared with other, more task-specific (ie, walking) activities.

Research Recommendation 5: Future studies should strongly consider evaluation of circuit and combined training interventions that carefully delineate the amounts, types, and intensities of interventions compared with a matched duration therapy that could reasonably be expected to improve walking function.

Research Recommendation 6: Further studies are required to verify the results of selected positive studies incorporating VR systems during balance training, including potential comparative efficacy studies utilizing different gaming systems, and further details on amounts, types, and intensities of practice provided.

Research Recommendation 7: Further studies should evaluate the amounts and intensities (cardiovascular demands) of stepping activities during BWSTT to ensure patient's effort and volitional engagement.

Research Recommendation 8: Further studies should evaluate the amounts and intensities of stepping activities during experimental robotic therapies to ensure patient's effort and volitional engagement.

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REFERENCES

1. Mehrholz J, Elsner B, Werner C, Kugler J, Pohl M. Electromechanical-assisted training for walking after stroke: updated evidence. *Stroke*. 2013;44:e127-e128.
2. Mehrholz J, Pohl M, Elsner B. Treadmill training and body weight support for walking after stroke. *Cochrane Database Syst Rev*. 2014;(1):CD002840.
3. States RA, Salem Y, Pappas E. Overground gait training for individuals with chronic stroke: a Cochrane systematic review. *J Neurol Phys Ther*. 2009;33:179-186.
4. Pollock A, Baer G, Pomeroy V, Langhorne P. Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke. *Cochrane Database Syst Rev*. 2007:(1):CD001920.
5. Turner-Stokes L, Disler PB, Nair A, Wade DT. Multi-disciplinary rehabilitation for acquired brain injury in adults of working age. *Cochrane Database Syst Rev*. 2005:(3):CD004170.
6. Mehrholz J, Kugler J, Pohl M. Locomotor training for walking after spinal cord injury. *Cochrane Database Syst Rev*. 2012;11:CD006676. doi:10.1002/14651858.CD006676.pub3.
7. Bland DC, Zampieri C, Damiano DL. Effectiveness of physical therapy for improving gait and balance in individuals with traumatic brain injury: a systematic review. *Brain Inj*. 2011; 25(7-8):664-679. doi:10.3109/02699052.2011.576306.
8. Lang CE, MacDonald JR, Gnip C. Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. *J Neurol Phys Ther*. 2007;31:3-10.
9. Kimberley TJ, Samargia S, Moore LG, Shakya JK, Lang CE. Comparison of amounts and types of practice during rehabilitation for traumatic brain injury and stroke. *J Rehabil Res Dev*. 2010;47:851-862.
10. Lang CE, Macdonald JR, Reisman DS, et al. Observation of amounts of movement practice provided during stroke rehabilitation. *Arch Phys Med Rehabil*. 2009;90:1692-1698.
11. Scrivener K, Sherrington C, Schurr K. Exercise dose and mobility outcome in a comprehensive stroke unit: description and prediction from a prospective cohort study. *J Rehabil Med*. 2012;44:824-829.
12. Zbogar D, Eng JJ, Miller WC, Krassioukov AV, Verrier MC. Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. *Spinal Cord*. 2017;55:172-179.
13. Prajapati SK, Mansfield A, Gage WH, Brooks D, McIlroy WE. Cardiovascular responses associated with daily walking in subacute stroke. *Stroke Res Treat*. 2013;2013:612458.
14. Zbogar D, Eng JJ, Noble JW, Miller WC, Krassioukov AV, Verrier MC. Cardiovascular stress during inpatient spinal cord injury rehabilitation. *Arch Phys Med Rehabil*. 2017;98(12):2449-2456.
15. Kuys S, Brauer S, Ada L. Routine physiotherapy does not induce a cardiorespiratory training effect post-stroke, regardless of walking ability. *Physiother Res Int*. 2006;11:219-227.
16. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *J Speech Lang Hear Res*. 2008;51:S225-S239.
17. Hornby TG, Straube DS, Kinnaird CR, et al. Importance of specificity, amount, and intensity of locomotor training to improve ambulatory function in patients poststroke. *Top Stroke Rehabil*. 2011;18:293-307.
18. Katch VL, McArdle WD, Katch FI. *Essentials of Exercise Physiology*. Baltimore, MD: Lippincott Williams & Williams; 2011.
19. Schmidt R, Lee T. *Motor Control and Learning: A Behavioral Emphasis*. 3rd ed. Champaign, IL: Human Kinetics Inc; 1999.
20. Roger VL, Go AS, Lloyd-Jones DM, et al. Executive summary: heart disease and stroke statistics—2012 update: a report from the American Heart Association. *Circulation*. 2012;125:188-197.
21. Roger VL, Go AS, Lloyd-Jones DM, et al. Heart disease and stroke statistics—2012 update: a report from the American Heart Association. *Circulation*. 2012;125:e2-e220.
22. Spinal cord injury (SCI) facts and figures at a glance. https://www.nscisc.uab.edu/Public/Facts%20and%20Figures%202019%20-%20Final.pdf. Published 2018. Accessed November 25, 2019.
23. Corrigan JD, Hammond FM. Traumatic brain injury as a chronic health condition. *Arch Phys Med Rehabil*. 2013;94:1199-1201.
24. Moore JL, Roth EJ, Killian C, Hornby TG. Locomotor training improves daily stepping activity and gait efficiency in individuals poststroke who have reached a "plateau" in recovery. *Stroke*. 2010;41:129-135.
25. Bobath B. *Adult Hemiplegia: Evaluation and Treatment*. 3rd ed. Oxford, England: Butterworth-Heinemann; 1990.
26. https://ibita.org/ibita-courses/. Published 2019.
27. Duncan P, Studenski S, Richards L, et al. Randomized clinical trial of therapeutic exercise in subacute stroke. *Stroke*. 2003;34:2173-2180.
28. Duncan PW, Sullivan KJ, Behrman AL, et al. Protocol for the Locomotor Experience Applied Post-stroke (LEAPS) trial: a randomized controlled trial. *BMC Neurol*. 2007;7:39.
29. Duncan PW, Sullivan KJ, Behrman AL, et al. Body-weight-supported treadmill rehabilitation after stroke. *N Engl J Med*. 2011;364:2026-2036.
30. Rose D, Paris T, Crews E, et al. Feasibility and effectiveness of circuit training in acute stroke rehabilitation. *Neurorehabil Neural Repair*. 2011;25:140-148.
31. Plummer P, Behrman AL, Duncan PW, et al. Effects of stroke severity and training duration on locomotor recovery after stroke: a pilot study. *Neurorehabil Neural Repair*. 2007;21:137-151.
32. Sullivan K, Knowlton BJ, Dobkin BH. Step training with body weight support: effect of treadmill speed and practice paradigms on poststroke locomotor recovery. *Arch Phys Med Rehabil*. 2002;83:683-691.
33. Pohl M, Mehrholz J, Ritschel C, Ruckriem S. Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: a randomized controlled trial. *Stroke*. 2002;33:553-558.
34. Macko RF, Ivey FM, Forrester LW, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. *Stroke*. 2005;36:2206-2211.
35. Visintin M, Barbeau H, Korner-Bitensky N, Mayo NE. A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. *Stroke*. 1998;29:1122-1128.
36. Combs-Miller SA, Kalpathi Parameswaran A, Colburn D, et al. Body weight-supported treadmill training vs. overground walking training for persons with chronic stroke: a pilot randomized controlled trial. *Clin Rehabil*. 2014;28:873-884.
37. Hornby TG, Campbell DD, Kahn JH, Demott T, Moore JL, Roth HR. Enhanced gait-related improvements after therapist- versus robotic-assisted locomotor training in subjects with chronic stroke: a randomized controlled study. *Stroke*. 2008;39:1786-1792.
38. Hidler J, Nichols D, Pelliccio M, et al. Multicenter randomized clinical trial evaluating the effectiveness of the Lokomat in subacute stroke. *Neurorehabil Neural Repair*. 2009;23:5-13.
39. Werner C, Von Frankenberg S, Treig T, Konrad M, Hesse S. Treadmill training with partial body weight support and an electromechanical gait trainer for restoration of gait in subacute stroke patients: a randomized crossover study. *Stroke*. 2002;33:2895-2901.
40. Holleran CL, Straube DD, Kinnaird CR, Leddy AL, Hornby TG. Feasibility and potential efficacy of high-intensity stepping training in variable contexts in subacute and chronic stroke. *Neurorehabil Neural Repair*. 2014;28:643-651.

41. Ada L, Dean CM, Hall JM, Bampton J, Crompton S. A treadmill and overground walking program improves walking in persons residing in the community after stroke: a placebo-controlled, randomized trial. *Arch Phys Med Rehabil*. 2003;84:1486-1491.
42. Mehrholz J, Elsner B, Werner C, Kugler J, Pohl M. Electromechanical-assisted training for walking after stroke. *Cochrane Database Syst Rev.* 2013;7:CD006185.
43. States RA, Pappas E, Salem Y. Overground physical therapy gait training for chronic stroke patients with mobility deficits. *Cochrane Database Syst Rev*. 2009:(3):CD006075.
44. Lohse KR, Pathania A, Wegman R, Boyd LA, Lang CE. On the reporting of experimental and control therapies in stroke rehabilitation trials: a systematic review. *Arch Phys Med Rehabil*. 2018;99:1424-1432.
45. Cha J, Heng C, Reinkensmeyer DJ, Roy RR, Edgerton VR, De Leon RD. Locomotor ability in spinal rats is dependent on the amount of activity imposed on the hindlimbs during treadmill training. *J Neurotrauma*. 2007;24:1000-1012.
46. De Leon RD, Hodgson JA, Roy RR, Edgerton VR. Locomotor capacity attributable to step training versus spontaneous recovery after spinalization in adult cats. *J Neurophysiol*. 1998;79: 1329-1340.
47. De Leon RD, Hodgson JA, Roy RR, Edgerton VR. Full weight-bearing hindlimb standing following stand training in the adult spinal cat. *J Neurophysiol*. 1998;80:83-91.
48. Billinger SA, Boyne P, Coughenour E, Dunning K, Mattlage A. Does aerobic exercise and the FITT principle fit into stroke recovery? *Curr Neurol Neurosci Rep*. 2015;15:519.
49. About the CMS Innovation Center. About the CMS Innovation Center | Center for Medicare & Medicaid Innovation. https://innovation.cms.gov/About/index.html. Accessed November 25, 2019.
50. Bundled Payments for Care Improvement (BPCI) Initiative: General Information. Bundled Payments for Care Improvement (BPCI) Initiative: General Information | Center for Medicare & Medicaid Innovation. https://innovation.cms.gov/initiatives/Bundled-Payments/. Accessed November 25, 2019.
51. SNF PPS Payment Model Research. CMS. https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/SNFPPS/therapyresearch.html. Accessed November 25, 2019.
52. CMS Takes Action to Modernize Medicare Home Health. CMS. https://www.cms.gov/newsroom/press-releases/cms-takes-action-modernize-medicare-home-health. Accessed November 25, 2019.
53. Duncan PW, Lai SM, Keighley J. Defining post-stroke recovery: implications for design and interpretation of drug trials. *Neuropharmacology*. 2000;39:835-841.
54. Crozier KS, Cheng LL, Graziani V, Zorn G, Herbison G, Ditunno JF Jr. Spinal cord injury: prognosis for ambulation based on quadriceps recovery. *Paraplegia*. 1992;30:762-767.
55. Jorgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Stoier M, Olsen TS. Outcome and time course of recovery in stroke. Part I: outcome. The Copenhagen Stroke Study. *Arch Phys Med Rehabil*. 1995;76:399-405.
56. Zorner B, Blanckenhorn WU, Dietz V, Group E-SS, Curt A. Clinical algorithm for improved prediction of ambulation and patient stratification after incomplete spinal cord injury. *J Neurotrauma*. 2010;27:241-252.
57. Curt A, Van Hedel HJ, Klaus D, Dietz V; EM-SCI Study Group. Recovery from a spinal cord injury: significance of compensation, neural plasticity, and repair. *J Neurotrauma*. 2008;25:677-685.
58. Dobkin BH. Motor rehabilitation after stroke, traumatic brain, and spinal cord injury: common denominators within recent clinical trials. *Curr Opin Neurol*. 2009;22:563-569.
59. Cramer SC, Sur M, Dobkin BH, et al. Harnessing neuroplasticity for clinical applications. *Brain*. 2011;134(6):1591-1609.
60. Dietz V, Fouad K. Restoration of sensorimotor functions after spinal cord injury. *Brain*. 2014;137(pt 3):654-667.
61. Holleran CL, Hennessey PW, Leddy AL, et al. High-intensity variable stepping training in patients with motor incomplete spinal cord injury: a case series. *J Neurol Phys The*. 2018;42:94-101.
62. Freivogel S, Mehrholz J, Husak-Sotomayor T, Schmalohr D. Gait training with the newly developed "LokoHelp"-system is feasible for non-ambulatory patients after stroke, spinal cord and brain injury. A feasibility study. *Brain Inj*. 2008;22:625-632.
63. Gracies JM, Esquenazi A, Brashear A, et al. Efficacy and safety of abobotulinumtoxinA in spastic lower limb: randomized trial and extension. *Neurology*. 2017;89:2245-2253.
64. Gracies JM, Brashear A, Jech R, et al. Safety and efficacy of abobotulinumtoxinA for hemiparesis in adults with upper limb spasticity after stroke or traumatic brain injury: a double-blind randomised controlled trial. *Lancet Neurol*. 2015;14:992-1001.
65. Saraf P, Rafferty MR, Moore JL, et al. Daily stepping in individuals with motor incomplete spinal cord injury. *Phys Ther*. 2010;90:224-235.
66. Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. *Arch Phys Med Rehabil*. 2005;86:1552-1556.
67. Patterson SL, Forrester LW, Rodgers MM, et al. Determinants of walking function after stroke: differences by deficit severity. *Arch Phys Med Rehabil*. 2007;88:115-119.
68. Danks KA, Pohlig RT, Roos M, Wright TR, Reisman DS. Relationship between walking capacity, biopsychosocial factors, self-efficacy, and walking activity in persons poststroke. *J Neurol Phys Ther*. 2016;40:232-238.
69. Middleton A, Fritz SL, Lusardi M. Walking speed: the functional vital sign. *J Aging Phys Act*. 2015;23:314-322.
70. Moore JL, Potter K, Blankshain K, Kaplan SL, O'Dwyer LC, Sullivan JE. A core set of outcome measures for adults with neurologic conditions undergoing rehabilitation: A CLINICAL PRACTICE GUIDELINE. *J Neurol Phys Ther*. 2018;42:174-220.
71. Howlett OA, Lannin NA, Ada L, McKinstry C. Functional electrical stimulation improves activity after stroke: a systematic review with meta-analysis. *Arch Phy Med Rehabil*. 2015;96:934-943.
72. Kluding PM, Dunning K, O'Dell MW, et al. Foot drop stimulation versus ankle foot orthosis after stroke: 30-week outcomes. *Stroke*. 2013;44:1660-1669.
73. Everaert DG, Stein RB, Abrams GM, et al. Effect of a foot-drop stimulator and ankle-foot orthosis on walking performance after stroke: a multicenter randomized controlled trial. *Neurorehabil Neural Repair*. 2013;27:579-591.
74. Bethoux F, Rogers HL, Nolan KJ, et al. The effects of peroneal nerve functional electrical stimulation versus ankle-foot orthosis in patients with chronic stroke: a randomized controlled trial. *Neurorehabil Neural Repair*. 2014;28:688-697.
75. Globas C, Becker C, Cerny J, et al. Chronic stroke survivors benefit from high-intensity aerobic treadmill exercise: a randomized control trial. *Neurorehabil Neural Repair*. 2012;26:85-95.
76. Gordon CD, Wilks R, McCaw-Binns A. Effect of aerobic exercise (walking) training on functional status and health-related quality of life in chronic stroke survivors: a randomized controlled trial. *Stroke*. 2013;44:1179-1181.
77. Luft AR, Macko RF, Forrester LW, et al. Treadmill exercise activates subcortical neural networks and improves walking after stroke: a randomized controlled trial. *Stroke*. 2008;39:3341-3350.
78. Boyne P, Dunning K, Carl D, et al. High-intensity interval training and moderate-intensity continuous training in ambulatory chronic stroke: feasibility study. *Phys Ther*. 2016;96:1533-1544.
79. Holleran CL, Rodriguez KS, Echauz A, Leech KA, Hornby TG. Potential contributions of training intensity on locomotor performance in individuals with chronic stroke. *J Neurol Phys Ther*. 2015;39:95-102.
80. Ivey FM, Stookey AD, Hafer-Macko CE, Ryan AS, Macko RF. Higher treadmill training intensity to address functional aerobic impairment after stroke. *J Stroke Cerebrovasc Dis*. 2015;24:2539-2546.
81. Munari D, Pedrinolla A, Smania N, et al. High-intensity treadmill training improves gait ability, VO2peak and cost of walking in stroke survivors: preliminary results of a pilot randomized controlled trial. *Eur J Phys Rehabil Med*. 2016;54:408-418.

82. Yang JF, Musselman KE, Livingstone D, et al. Repetitive mass practice or focused precise practice for retraining walking after incomplete spinal cord injury? A pilot randomized clinical trial. *Neurorehabil Neural Repair*. 2014;28:314-324.
83. Cho KH, Lee WH. Virtual walking training program using a real-world video recording for patients with chronic stroke: a pilot study. *Am J Phys Med Rehabil.* 2013;92:371-380; quiz 380-382, 458.
84. Cho KH, Lee WH. Effect of treadmill training based real-world video recording on balance and gait in chronic stroke patients: a randomized controlled trial. *Gait Posture.* 2014;39:523-528.
85. Kang HK, Kim Y, Chung Y, Hwang S. Effects of treadmill training with optic flow on balance and gait in individuals following stroke: randomized controlled trials. *Clin Rehabil*. 2012;26:246-255.
86. Kim N, Park Y, Lee BH. Effects of community-based virtual reality treadmill training on balance ability in patients with chronic stroke. *J Phys Ther Sci*. 2015;27:655-658.
87. Yang YR, Tsai MP, Chuang TY, Sung WH, Wang RY. Virtual reality-based training improves community ambulation in individuals with stroke: a randomized controlled trial. *Gait Posture*. 2008;28:201-206.
88. Cho KH, Kim MK, Lee HJ, Lee WH. Virtual reality training with cognitive load improves walking function in chronic stroke patients. *Tohoku J Exp Med*. 2015;236:273-280.
89. Jaffe DL, Brown DA, Pierson-Carey CD, Buckley EL, Lew HL. Stepping over obstacles to improve walking in individuals with poststroke hemiplegia. *J Rehabil Res Dev.* 2004;41:283-292.
90. Kim N, Lee BH, Kim Y, Min W. Effects of virtual reality treadmill training on community balance confidence and gait in people post-stroke: a randomized controlled trial. *J Exp Stroke Translational Med*. 2016;1-9.
91. Flansbjer UB, Miller M, Downham D, Lexell J. Progressive resistance training after stroke: effects on muscle strength, muscle tone, gait performance and perceived participation. *J Rehabil Med*. 2008;40:42-48.
92. Severinsen K, Jakobsen JK, Pedersen AR, Overgaard K, Andersen H. Effects of resistance training and aerobic training on ambulation in chronic stroke. *Am J Phys Med Rehabil*. 2014;93:29-42.
93. Yang YR, Wang RY, Lin KH, Chu MY, Chan RC. Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. *Clin Rehabil*. 2006;20:860-870.
94. Bourbonnais D, Bilodeau S, Lepage Y, Beaudoin N, Gravel D, Forget R. Effect of force-feedback treatments in patients with chronic motor deficits after a stroke. *Am J Phys Med Rehabil.* 2002;81:890-897.
95. Kim CM, Eng JJ, MacIntyre DL, Dawson AS. Effects of isokinetic strength training on walking in persons with stroke: a double-blind controlled pilot study. *J Stroke Cerebrovasc Dis* 2001;10:265-273.
96. Ouellette MM, LeBrasseur NK, Bean JF, et al. High-intensity resistance training improves muscle strength, self-reported function, and disability in long-term stroke survivors. *Stroke*. 2004;35:1404-1409.
97. Jayaraman A, Thompson CK, Rymer WZ, Hornby TG. Short-term maximal-intensity resistance training increases volitional function and strength in chronic incomplete spinal cord injury: a pilot study. *J Neurol Phys Ther.* 2013;37:112-117.
98. Kim SJ, Cho HY, Kim KH, Lee SM. Effects of ankle biofeedback training on strength, balance, and gait in patients with stroke. *J Phys Ther Sci.* 2016;28:2596-2600.
99. Labruyère R, van Hedel HJ. Strength training versus robot-assisted gait training after incomplete spinal cord injury: a randomized pilot study in patients depending on walking assistance. *J Neuroeng Rehabil* 2014;11:4.
100. Clark DJ, Patten C. Eccentric versus concentric resistance training to enhance neuromuscular activation and walking speed following stroke. *Neurorehabil Neural Repair.* 2013;27:335-344.
101. Bang DH, Son YL. Effect of intensive aerobic exercise on respiratory capacity and walking ability with chronic stroke patients: a randomized controlled pilot trial. *J Phys Ther Sci*. 2016;28:2381-2384.
102. Jin H, Jiang Y, Wei Q, Wang B, Ma G. Intensive aerobic cycling training with lower limb weights in Chinese patients with chronic stroke: discordance between improved cardiovascular fitness and walking ability. *Disabil Rehabil*. 2012;34:1665-1671.
103. Jin H, Jiang Y, Wei Q, Chen L, Ma G. Effects of aerobic cycling training on cardiovascular fitness and heart rate recovery in patients with chronic stroke. *Neurorehabilitation*. 2013;32:327-335.
104. Song GB, Park EC. Effect of virtual reality games on stroke patients' balance, gait, depression, and interpersonal relationships. *J Phys Ther Sci*. 2015;27:2057-2060.
105. Dean CM, Richards CL, Malouin F. Task-related circuit training improves performance of locomotor tasks in chronic stroke: a randomized, controlled pilot trial. *Arch Phys Med Rehabil*. 2000;81:409-417.
106. Moore SA, Jakovljevic DG, Ford GA, Rochester L, Trenell MI. Exercise induces peripheral muscle but not cardiac adaptations after stroke: a randomized controlled pilot trial. *Arch Phys Med Rehabil*. 2016;97:596-603.
107. Mudge S, Barber PA, Stott NS. Circuit-based rehabilitation improves gait endurance but not usual walking activity in chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil.* 2009;90:1989-1996.
108. Pang MY, Eng JJ, Dawson AS, McKay HA, Harris JE. A community-based fitness and mobility exercise program for older adults with chronic stroke: a randomized, controlled trial. *J Am Geriatr Soc.* 2005;53:1667-1674.
109. Song HS, Kim JY, Park SD. Effect of the class and individual applications of task-oriented circuit training on gait ability in patients with chronic stroke. *J Phys Ther Sci*. 2015;27:187-189.
110. Vahlberg B, Cederholm T, Lindmark B, Zetterberg L, Hellstrom K. Short-term and long-term effects of a progressive resistance and balance exercise program in individuals with chronic stroke: a randomized controlled trial. *Disabil Rehabil*. 2017;39:1615-1622.
111. Hui-Chan CW, Ng SS, Mak MK. Effectiveness of a home-based rehabilitation programme on lower limb functions after stroke. *Hong Kong Med J*. 2009;15:42-46.
112. Lee YH, Park SH, Yoon ES, et al. Effects of combined aerobic and resistance exercise on central arterial stiffness and gait velocity in patients with chronic poststroke hemiparesis. *Am J Phys Med Rehabil*. 2015;94:687-695.
113. Tang A, Eng JJ, Krassioukov AV, et al. Exercise-induced changes in cardiovascular function after stroke: a randomized controlled trial. *Int J Stroke.* 2014;9:883-889.
114. Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B. Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. *Arch Phys Med Rehabil.* 1999;80:1211-1218.
115. Dean CM, Shepherd RB. Task-related training improves performance of seated reaching tasks after stroke. A randomized controlled trial. *Stroke*. 1997;28:722-728.
116. Kilinc M, Avcu F, Onursal O, Ayvat E, Savcun Demirci C, Aksu Yildirim S. The effects of Bobath-based trunk exercises on trunk control, functional capacity, balance, and gait: a pilot randomized controlled trial. *Top Stroke Rehabil*. 2016;23:50-58.
117. Chun JY, Seo JH, Park SH, et al. Effects of 3-dimensional lumbar stabilization training for balance in chronic hemiplegic stroke patients: a randomized controlled trial. *Ann Rehabil Med*. 2016;40:972-980.
118. Kim H, Kim YL, Lee SM. Effects of therapeutic Tai Chi on balance, gait, and quality of life in chronic stroke patients. *Int J Rehabil Res.* 2015;38:156-161.
119. Aruin AS, Rao N, Sharma A, Chaudhuri G. Compelled body weight shift approach in rehabilitation of individuals with chronic stroke. *Top Stroke Rehabil*. 2012;19:556-563.
120. Sheikh M, Azarpazhooh MR, Hosseini HA. Randomized comparison trial of gait training with and without compelled weight-

shift therapy in individuals with chronic stroke. *Clin Rehabil*. 2016;30:1088-1096.
121. You YY, Her JG, Ko T, Chung SH, Kim H. Effects of standing on one leg exercise on gait and balance of hemiplegia patients. *J Phys Ther Sci.* 2012;25:571-575.
122. Bang DH, Shin WS, Noh HJ, Song MS. Effect of unstable surface training on walking ability in stroke patients. *J Phys Ther Sci.* 2014;26:1689-1691.
123. Bayouk JF, Boucher JP, Leroux A. Balance training following stroke: effects of task-oriented exercises with and without altered sensory input. *Int J Rehabil Res.* 2006;29:51-59.
124. Bonan IV, Yelnik AP, Colle FM, et al. Reliance on visual information after stroke. Part II: effectiveness of a balance rehabilitation program with visual cue deprivation after stroke: a randomized controlled trial. *Arch Phys Med Rehabil*. 2004;85:274-278.
125. Brogårdh C, Flansbjer UB, Lexell J. No specific effect of whole-body vibration training in chronic stroke: a double-blind randomized controlled study. *Arch Phys Med Rehabil.* 2012;93:253-258.
126. Lau RW, Yip SP, Pang MY. Whole-body vibration has no effect on neuromotor function and falls in chronic stroke. *Med Sci Sports Exerc.* 2012;44:1409-1418.
127. Lee SW, Cho KH, Lee WH. Effect of a local vibration stimulus training programme on postural sway and gait in chronic stroke patients: a randomized controlled trial. *Clin Rehabil*. 2013;27:921-931.
128. Liao LR, Ng GY, Jones AY, Huang MZ, Pang MY. Whole-body vibration intensities in chronic stroke: a randomized controlled trial. *Med Sci Sports Exerc*. 2016;48:1227-1238.
129. Kim JH, Jang SH, Kim CS, Jung JH, You JH. Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study. *Am J Phys Med Rehabil.* 2009;88:693-701.
130. Lee CH, Kim Y, Lee BH. Augmented reality-based postural control training improves gait function in patients with chronic stroke: randomized clinical trial. *Hong Kong Physiother J*. 2014;32:51-57.
131. Park YH, Lee CH, Lee BH. Clinical usefulness of the virtual reality-based postural control training on the gait ability in patients with stroke. *J Exerc Rehabil*. 2013;9:489-494.
132. Yom C, Cho HY, Lee B. Effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait of stroke patients. *J Phys Ther Sci.* 2015;27:845-849.
133. Chung E, Lee BH, Hwang S. Core stabilization exercise with real-time feedback for chronic hemiparetic stroke: a pilot randomized controlled trials. *Restor Neurol Neurosci.* 2014;32:313-321.
134. Gil-Gomez JA, Llorens R, Alcaniz M, Colomer C. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. *J Neuroeng Rehabil.* 2011;8:30.
135. Llorens R, Gil-Gomez JA, Alcaniz M, Colomer C, Noe E. Improvement in balance using a virtual reality-based stepping exercise: a randomized controlled trial involving individuals with chronic stroke. *Clin Rehabil*. 2015;29:261-268.
136. Fritz SL, Peters DM, Merlo AM, Donley J. Active video-gaming effects on balance and mobility in individuals with chronic stroke: a randomized controlled trial. *Top Stroke Rehabil*. 2013;20:218-225.
137. Alexeeva N, Sames C, Jacobs PL, et al. Comparison of training methods to improve walking in persons with chronic spinal cord injury: a randomized clinical trial. *J Spinal Cord Med.* 2011;34:362-379.
138. Brown TH, Mount J, Rouland BL, Kautz KA, Barnes RM, Kim J. Body weight-supported treadmill training versus conventional gait training for people with chronic traumatic brain injury. *J Head Trauma Rehabil.* 2005;20:402-415.
139. Middleton A, Merlo-Rains A, Peters DM, et al. Body weight-supported treadmill training is no better than overground training for individuals with chronic stroke: a randomized controlled trial. *Top Stroke Rehabil*. 2014;21:462-476.
140. Suputtitada A, Yooktanan P, Rarerng-Ying T. Effect of partial body weight support treadmill training in chronic stroke patients. *J Med Assoc Thai*. 2004;87(suppl 2):S107-S111.
141. Lucareli PR, Lima MO, Lima FP, de Almeida JG, Brech GC, D'Andrea Greve JM. Gait analysis following treadmill training with body weight support versus conventional physical therapy: a prospective randomized controlled single blind study. *Spinal Cord.* 2011;49:1001-1007.
142. Ribeiro T, Britto H, Oliveira D, Silva E, Galvao E, Lindquist A. Effects of treadmill training with partial body weight support and the proprioceptive neuromuscular facilitation method on hemiparetic gait: a randomized controlled study. *Eur J Phys Rehabil Med.* 2013;49:451-461.
143. Yen CL, Wang RY, Liao KK, Huang CC, Yang YR. Gait training induced change in corticomotor excitability in patients with chronic stroke. *Neurorehabil Neural Repair*. 2008;22:22-30.
144. Takao T, Tanaka N, Iizuka N, Saitou H, Tamaoka A, Yanagi H. Improvement of gait ability with a short-term intensive gait rehabilitation program using body weight support treadmill training in community dwelling chronic poststroke survivors. *J Phys Ther Sci*. 2015;27:159-163.
145. Bang DH, Shin WS. Effects of robot-assisted gait training on spatiotemporal gait parameters and balance in patients with chronic stroke: a randomized controlled pilot trial. *Neurorehabilitation*. 2016;38:343-349.
146. Buesing C, Fisch G, O'Donnell M, et al. Effects of a wearable exoskeleton stride management assist system (SMA(R)) on spatiotemporal gait characteristics in individuals after stroke: a randomized controlled trial. *J Neuroeng Rehabil.* 2015;12:69.
147. Esquenazi A, Lee S, Packel AT, Braitman L. A randomized comparative study of manually assisted versus robotic-assisted body weight supported treadmill training in persons with a traumatic brain injury. *PM R.* 2013;5:280-290.
148. Field-Fote EC, Roach KE. Influence of a locomotor training approach on walking speed and distance in people with chronic spinal cord injury: a randomized clinical trial. *Phys Ther*. 2011;91:48-60.
149. Peurala SH, Tarkka IM, Pitkanen K, Sivenius J. The effectiveness of body weight-supported gait training and floor walking in patients with chronic stroke. *Arch Phys Med Rehabil.* 2005;86:1557-1564.
150. Westlake KP, Patten C. Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke. *J Neuroeng Rehabil.* 2009;6:18.
151. Stein J, Bishop L, Stein DJ, Wong CK. Gait training with a robotic leg brace after stroke: a randomized controlled pilot study. *Am J Phys Med Rehabil.* 2014;93:987-994.
152. Ucar DE, Paker N, Bugdayci D. Lokomat: a therapeutic chance for patients with chronic hemiplegia. *Neurorehabilitation*. 2014;34:447-453.
153. Forrester LW, Roy A, Hafer-Macko C, Krebs HI, Macko RF. Task-specific ankle robotics gait training after stroke: a randomized pilot study. *J Neuroeng Rehabil.* 2016;13:51.
154. Lam T, Pauhl K, Ferguson A, et al. Training with robot-applied resistance in people with motor-incomplete spinal cord injury: pilot study. *J Rehabil Res Dev.* 2015;52:113-129.
155. Wu M, Landry JM, Kim J, Schmit BD, Yen SC, Macdonald J. Robotic resistance/assistance training improves locomotor function in individuals poststroke: a randomized controlled study. *Arch Phys Med Rehabil.* 2014;95:799-806.
156. Wu M, Landry JM, Kim J, et al. Repeat exposure to leg swing perturbations during treadmill training induces long-term retention of increased step length in human SCI: a pilot randomized controlled study. *Am J Phys Med Rehabil.* 2016;95:911-920.
157. Wu M, Landry JM, Schmit BD, Hornby TG, Yen SC. Robotic resistance treadmill training improves locomotor function in human spinal cord injury: a pilot study. *Arch Phys Med Rehabil.* 2012;93:782-789.
158. Shiffman RN, Michel G, Rosenfeld RM, Davidson C. Building better guidelines with BRIDGE-Wiz: development and evaluation

of a software assistant to promote clarity, transparency, and implementability. *J Am Med Inform Assoc*. 2012;19:94-101.
159. Laver K, Ratcliffe J, George S, et al. Early rehabilitation management after stroke: what do stroke patients prefer? *J Rehabil Med.* 2011;43:354-358.
160. Laver K, Ratcliffe J, George S, Burgess L, Crotty M. Is the Nintendo Wii Fit really acceptable to older people? A discrete choice experiment. *BMC Geriatr*. 2011;11:64.
161. Laver K, Ratcliffe J, George S, Lester L, Crotty M. Preferences for rehabilitation service delivery: a comparison of the views of patients, occupational therapists and other rehabilitation clinicians using a discrete choice experiment. *Aust Occup Ther J*. 2013;60:93-100.
162. Geidl W, Knocke K, Schupp W, Pfeifer K. Measuring stroke patients' exercise preferences using a discrete choice experiment. *Neurol Int*. 2018;10:6993.
163. Krishnan S, Pappadis MR, Weller SC, Fisher SR, Hay CC, Reistetter TA. Patient-centered mobility outcome preferences according to individuals with stroke and caregivers: a qualitative analysis. *Disabil Rehabil.* 2018;40:1401-1409.
164. Combs SA, Van Puymbroeck M, Altenburger PA, Miller KK, Dierks TA, Schmid AA. Is walking faster or walking farther more important to persons with chronic stroke? *Disabil Rehabil.* 2013;35:860-867.
165. Holleran CL, Fogo J, Combs-Miller SA, Hornby TG. *Community Mobility Method Selection in Individuals With Chronic Motor Incomplete Spinal Cord Injury*. Anaheim, CA: American Physical Therapy Association, Combined Section Meeting; 2016.
166. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. *JAMA*. 2011;305:50-58.
167. Resnick B, Michael K, Shaughnessy M, Kopunek S, Nahm ES, Macko RF. Motivators for treadmill exercise after stroke. *Top Stroke Rehabil*. 2008;15:494-502.
168. Pandey A, Parashar A, Kumbhani D, et al. Exercise training in patients with heart failure and preserved ejection fraction: meta-analysis of randomized control trials. *Circ Heart Fail.* 2015;8:33-40.
169. Taylor RS, Brown A, Ebrahim S, et al. Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials. *Am J Med*. 2004;116:682-692.
170. Dhamoon MS, Tai W, Boden-Albala B, et al. Risk of myocardial infarction or vascular death after first ischemic stroke: the Northern Manhattan Study. *Stroke*. 2007;38:1752-1758.
171. Macko RF, Ivey FM, Forrester LW. Task-oriented aerobic exercise in chronic hemiparetic stroke: training protocols and treatment effects. *Top Stroke Rehabil.* 2005;12:45-57.
172. Shumway-Cook A, Patla A, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental components of mobility disability in community-living older persons. *J Am Geriatr Soc.* 2003;51:393-398.
173. Shumway-Cook A, Patla AE, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental demands associated with community mobility in older adults with and without mobility disabilities. *Phys Ther*. 2002;82:670-681.
174. Balasubramanian CK, Clark DJ, Fox EJ. Walking adaptability after a stroke and its assessment in clinical settings. *Stroke Res Treat.* 2014;2014:591013.
175. Darekar A, McFadyen BJ, Lamontagne A, Fung J. Efficacy of virtual reality-based intervention on balance and mobility disorders post-stroke: a scoping review. *J Neuroeng Rehabil.* 2015;12:46.
176. Levin MF, Weiss PL, Keshner EA. Emergence of virtual reality as a tool for upper limb rehabilitation: incorporation of motor control and motor learning principles. *Phys Ther*. 2015;95:415-425.
177. Lewis GN, Rosie JA. Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users? *Disabil Rehabil.* 2012;34:1880-1886.
178. Awad LN, Binder-Macleod SA, Pohlig RT, Reisman DS. Paretic propulsion and trailing limb angle are key determinants of long-distance walking function after stroke. *Neurorehabil Neural Repair.* 2015;29:499-508.
179. Madhavan S, Krishnan C, Jayaraman A, Rymer WZ, Stinear JW. Corticospinal tract integrity correlates with knee extensor weakness in chronic stroke survivors. *Clin Neurophysiol*. 2011;122:1588-1594.
180. Newham DJ, Hsiao SF. Knee muscle isometric strength, voluntary activation and antagonist co-contraction in the first six months after stroke. *Disabil Rehabil*. 2001;23:379-386.
181. Knarr BA, Ramsay JW, Buchanan TS, Higginson JS, Binder-Macleod SA. Muscle volume as a predictor of maximum force generating ability in the plantar flexors post-stroke. *Muscle Nerve*. 2013;48:971-976.
182. Shields RK. Muscular, skeletal, and neural adaptations following spinal cord injury. *J Orthop Sports Phys Ther*. 2002;32:65-74.
183. Lee SS, Spear S, Rymer WZ. Quantifying changes in material properties of stroke-impaired muscle. *Clin Biomech (Bristol, Avon)*. 2015;30:269-275.
184. Diong J, Harvey LA, Kwah LK, et al. Gastrocnemius muscle contracture after spinal cord injury: a longitudinal study. *Am J Phys Med Rehabil.* 2013;92:565-574.
185. Diong JH, Herbert RD, Harvey LA, et al. Passive mechanical properties of the gastrocnemius after spinal cord injury. *Muscle Nerve*. 2012;46:237-245.
186. Biering-Sorensen B, Kristensen IB, Kjaer M, Biering-Sorensen F. Muscle after spinal cord injury. *Muscle Nerve*. 2009;40:499-519.
187. Hafer-Macko CE, Ryan AS, Ivey FM, Macko RF. Skeletal muscle changes after hemiparetic stroke and potential beneficial effects of exercise intervention strategies. *J Rehabil Res Dev.* 2008;45:261-272.
188. Olney SJ, Griffin MP, McBride ID. Temporal, kinematic, and kinetic variables related to gait speed in subjects with hemiplegia: a regression approach. *Phys Ther*. 1994;74:872-885.
189. Bowden MG, Balasubramanian CK, Neptune RR, Kautz SA. Anterior-posterior ground reaction forces as a measure of paretic leg contribution in hemiparetic walking. *Stroke*. 2006;37:872-876.
190. Patten C, Lexell J, Brown HE. Weakness and strength training in persons with poststroke hemiplegia: rationale, method, and efficacy. *J Rehabil Res Dev.* 2004;41:293-312.
191. Pak S, Patten C. Strengthening to promote functional recovery poststroke: an evidence-based review. *Top Stroke Rehabil*. 2008;15:177-199.
192. Jacobs PL, Nash MS. Exercise recommendations for individuals with spinal cord injury. *Sports Med*. 2004;34:727-751.
193. Kitzman DW, Brubaker PH, Morgan TM, Stewart KP, Little WC. Exercise training in older patients with heart failure and preserved ejection fraction: a randomized, controlled, single-blind trial. *Circ Heart Fail*. 2010;3:659-667.
194. Winding KM, Munch GW, Iepsen UW, Van Hall G, Pedersen BK, Mortensen SP. The effect on glycaemic control of low-volume high-intensity interval training versus endurance training in individuals with type 2 diabetes. *Diabetes Obes Metab*. 2018;20:1131-1139.
195. Bochkezanian V, Raymond J, de Oliveira CQ, Davis GM. Can combined aerobic and muscle strength training improve aerobic fitness, muscle strength, function and quality of life in people with spinal cord injury? A systematic review. *Spinal Cord*. 2015;53:418-431.
196. van de Port IG, Wevers L, Roelse H, van Kats L, Lindeman E, Kwakkel G. Cost-effectiveness of a structured progressive task-oriented circuit class training programme to enhance walking competency after stroke: the protocol of the FIT-Stroke trial. *BMC Neurol*. 2009;9:43.
197. Wevers L, van de Port I, Vermue M, Mead G, Kwakkel G. Effects of task-oriented circuit class training on walking competency after stroke: a systematic review. *Stroke*. 2009;40:2450-2459.
198. Tang A, Eng JJ, Krassioukov AV, Tsang TS, Liu-Ambrose T. High- and low-intensity exercise do not improve cognitive function after

stroke: a randomized controlled trial. *J Rehabil Med.* 2016;48: 841-846.
199. Kendrick D, Kumar A, Carpenter H, et al. Exercise for reducing fear of falling in older people living in the community. *Cochrane Database Syst Rev*. 2014;(11):CD009848.
200. Xu T, Clemson L, O'Loughlin K, Lannin NA, Dean C, Koh G. Risk factors for falls in community stroke survivors: a systematic review and meta-analysis. *Arch Phys Med Rehabil.* 2018;99:563-573. e5.
201. Nadeau S, Duclos C, Bouyer L, Richards CL. Guiding task-oriented gait training after stroke or spinal cord injury by means of a biomechanical gait analysis. *Prog Brain Res.* 2011;192:161-180.
202. Hesse S, Bertelt C, Jahnke MT, et al. Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. *Stroke*. 1995;26:976-981.
203. Finch L, Barbeau H, Arsenault B. Influence of body weight support on normal human gait: development of a gait retraining strategy. *Phys Ther*. 1991;71:842-855; discussion 855-856.
204. Barbeau H, Wainberg M, Finch L. Description and application of a system for locomotor rehabilitation. *Med Biol Eng Comput*. 1987;25:341-344.
205. Visintin M, Barbeau H. The effects of body weight support on the locomotor pattern of spastic paretic patients. *Can J Neurol Sci*. 1989;16:315-325.
206. Yagura H, Hatakenaka M, Miyai I. Does therapeutic facilitation add to locomotor outcome of body weight–supported treadmill training in nonambulatory patients with stroke? A randomized controlled trial. *Arch Phys Med Rehabil.* 2006;87:529-535.
207. Wernig A, Muller S, Nanassy A, Cagol E. Laufband therapy based on 'rules of spinal locomotion' is effective in spinal cord injured persons. *Eur J Neurosci.* 1995;7:823-829.
208. Behrman AL, Harkema SJ. Locomotor training after human spinal cord injury: a series of case studies. *Phys Ther*. 2000;80:688-700.
209. Nadeau S, Gravel D, Arsenault AB, Bourbonnais D. Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. *Clin Biomech (Bristol, Avon).* 1999;14:125-135.
210. Colombo G, Joerg M, Schreier R, Dietz V. Treadmill training of paraplegic patients using a robotic orthosis. *J Rehabil Res Dev.* 2000;37:693-700.
211. Colombo G, Wirz M, Dietz V. Driven gait orthosis for improvement of locomotor training in paraplegic patients. *Spinal Cord.* 2001;39:252-255.
212. Hesse S, Sarkodie-Gyan T, Uhlenbrock D. Development of an advanced mechanised gait trainer, controlling movement of the centre of mass, for restoring gait in non-ambulant subjects. *Biomed Tech (Berl)*. 1999;44:194-201.
213. Hesse S, Schattat N, Mehrholz J, Werner C. Evidence of end-effector based gait machines in gait rehabilitation after CNS lesion. *Neurorehabilitation*. 2013;33:77-84.
214. Israel JF, Campbell DD, Kahn JH, Hornby TG. Metabolic costs and muscle activity patterns during robotic- and therapist-assisted treadmill walking in individuals with incomplete spinal cord injury. *Phys Ther*. 2006;86:1466-1478.
215. Bang DH, Shin WS, Kim SY, Choi JD. The effects of action observational training on walking ability in chronic stroke patients: a double-blind randomized controlled trial. *Clin Rehabil*. 2013;27:1118-1125.
216. Kim JH, Lee BH. Action observation training for functional activities after stroke: a pilot randomized controlled trial. *Neurorehabilitation*. 2013;33:565-574.
217. Sharp KG, Gramer R, Butler L, Cramer SC, Hade E, Page SJ. Effect of overground training augmented by mental practice on gait velocity in chronic, incomplete spinal cord injury. *Arch Phys Med Rehabil.* 2014;95:615-621.
218. Paoloni M, Mangone M, Scettri P, Procaccianti R, Cometa A, Santilli V. Segmental muscle vibration improves walking in chronic stroke patients with foot drop: a randomized controlled trial. *Neurorehabil Neural Repair*. 2010;24:254-262.
219. Rydwik E, Eliasson S, Akner G. The effect of exercise of the affected foot in stroke patients—a randomized controlled pilot trial. *Clin Rehabil*. 2006;20:645-655.
220. Johannsen L, Wing AM, Pelton T, et al. Seated bilateral leg exercise effects on hemiparetic lower extremity function in chronic stroke. *Neurorehabil Neural Repair.* 2010;24:243-253.
221. Mirelman A, Bonato P, Deutsch JE. Effects of training with a robot-virtual reality system compared with a robot alone on the gait of individuals after stroke. *Stroke.* 2009;40:169-174.
222. Goodman RN, Rietschel JC, Roy A, et al. Increased reward in ankle robotics training enhances motor control and cortical efficiency in stroke. *J Rehabil Res Dev.* 2014;51:213-227.
223. In T, Lee K, Song C. Virtual reality reflection therapy improves balance and gait in patients with chronic stroke: randomized controlled trials. *Med Sci Monit.* 2016;22:4046-4053.
224. Cha Y, Kim Y, Hwang S, Chung Y. Intensive gait training with rhythmic auditory stimulation in individuals with chronic hemiparetic stroke: a pilot randomized controlled study. *Neurorehabilitation*. 2014;35:681-688.
225. Park J, Park SY, Kim YW, Woo Y. Comparison between treadmill training with rhythmic auditory stimulation and ground walking with rhythmic auditory stimulation on gait ability in chronic stroke patients: a pilot study. *Neurorehabilitation*. 2015;37:193-202.
226. Yang CH, Kim JH, Lee BH. Effects of real-time auditory stimulation feedback on balance and gait after stroke: a randomized controlled trial. *J Exp Stroke Trans Med.* 2016;9:1-5.
227. Park HJ, Oh DW, Kim SY, Choi JD. Effectiveness of community-based ambulation training for walking function of post-stroke hemiparesis: a randomized controlled pilot trial. *Clin Rehabil*. 2011;25:451-459.
228. Danks KA, Pohlig R, Reisman DS. Combining fast-walking training and a step activity monitoring program to improve daily walking activity after stroke: a preliminary study. *Arch Phys Med Rehabil.* 2016;97:S185-S193.
229. Gama GL, de Lucena Trigueiro LC, Simao CR, et al. Effects of treadmill inclination on hemiparetic gait: controlled and randomized clinical trial. *Am J Phys Med Rehabil*. 2015;94:718-727.
230. Chen IH, Yang YR, Chan RC, Wang RY. Turning-based treadmill training improves turning performance and gait symmetry after stroke. *Neurorehabil Neural Repair*. 2014;28:45-55.
231. Jeong YG, Koo JW. The effects of treadmill walking combined with obstacle-crossing on walking ability in ambulatory patients after stroke: a pilot randomized controlled trial. *Top Stroke Rehabil.* 2016;23:406-412.
232. Awad LN, Reisman DS, Pohlig RT, Binder-Macleod SA. Reducing the cost of transport and increasing walking distance after stroke: a randomized controlled trial on fast locomotor training combined with functional electrical stimulation. *Neurorehabil Neural Repair*. 2016;30:661-670.
233. Kang TW, Lee JH, Cynn HS. Six-week Nordic treadmill training compared with treadmill training on balance, gait, and activities of daily living for stroke patients: a randomized controlled trial. *J Stroke Cerebrovasc Dis*. 2016;25:848-856.
234. Yang YR, Chen YC, Lee CS, Cheng SJ, Wang RY. Dual-task-related gait changes in individuals with stroke. *Gait Posture.* 2007;25:185-190.
235. Park IM, Lee YS, Moon BM, Sim SM. A comparison of the effects of overground gait training and treadmill gait training according to stroke patients' gait velocity. *J Phys Ther Sci*. 2013;25:379-332.
236. Won SH, Kim JC, Oh DW. Effects of a novel walking training program with postural correction and visual feedback on walking function in patients with post-stroke hemiparesis. *J Phys Ther Sci*. 2015;27:2581-2583.
237. Druzbicki M, Guzik A, Przysada G, Kwolek A, Brzozowska-Magon A. Efficacy of gait training using a treadmill with and without visual biofeedback in patients after stroke: a randomized study. *J Rehabil Med*. 2015;47:419-425.
238. Hornby TG, Kinnaird CR, Holleran CL, Rafferty MR, Rodriguez KS, Cain JB. Kinematic, muscular, and metabolic responses during

exoskeletal-, elliptical-, or therapist-assisted stepping in people with incomplete spinal cord injury. *Phys Ther*. 2012;92:1278-1291.
239. Gottschall JS, Kram R. Energy cost and muscular activity required for propulsion during walking. *J Appl Physiol*. 2003;94:1766-1772.
240. Gottschall J, Kram R. Energy cost and muscular activity required for leg swing during walking. *J Appl Physiol*. 2005;99:23-30.
241. Rycroft-Malone J. Evidence-informed practice: from individual to context. *J Nurs Manag*. 2008;16:404-408.
242. Hornby TG, Holleran CL, Hennessy PW, et al. Variable intensive early walking poststroke (VIEWS): a randomized controlled trial. *Neurorehabil Neural Repair.* 2016;30:440-450.
243. Duncan PW, Sullivan KJ, Behrman AL, Rose DK. Tilson JK. *Locomotor Experience Applied Post-Stroke (LEAPS): What Does the Outcome of the LEAPS RCT Mean to the Physical Therapist?* New Orleans, LA: American Physical Therapy Association Combined Sections Meeting; 2011.
244. Sullivan KJ, Brown DA, Klassen T, et al. Effects of task-specific locomotor and strength training in adults who were ambulatory after stroke: results of the STEPS randomized clinical trial. *Phys Ther.* 2007;87:1580-1602; discussion 603-607.
245. Winstein CJ, Gardner ER, McNeal DR, Barto PS, Nicholson DE. Standing balance training: effect on balance and locomotion in hemiparetic adults. *Arch Phys Med Rehabil.* 1989;70:755-762.
246. Yavuzer G, Eser F, Karakus D, Karaoglan B, Stam HJ. The effects of balance training on gait late after stroke: a randomized controlled trial. *Clin Rehabil*. 2006;20:960-969.
247. Ada L, Dean CM, Morris ME, Simpson JM, Katrak P. Randomized trial of treadmill walking with body weight support to establish walking in subacute stroke: the MOBILISE trial. *Stroke*. 2010;41:1237-1242.
248. Dean CM, Ada L, Bampton J, Morris ME, Katrak PH, Potts S. Treadmill walking with body weight support in subacute non-ambulatory stroke improves walking capacity more than overground walking: a randomised trial. *J Physiother*. 2010;56:97-103.
249. Barbeau H, Visintin M. Optimal outcomes obtained with body-weight support combined with treadmill training in stroke subjects. *Arch Phys Med Rehabil*. 2003;84:1458-1465.
250. Billinger SA, Arena R, Bernhardt J, et al. Physical activity and exercise recommendations for stroke survivors: a statement for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2014;45:2532-2553.

APPENDIX: EVIDENCE TABLES

Evidence tables provide a brief summary of the available research evidence for a particular physical therapy strategy, with specific details for each article. Specific details include as follows: last name of first author and year (sample size); strength of the article, including the level of evidence (I or II) and the scored section (section B) from the CAT-EI (listed as the "tally"); population diagnosis; indication of significant differences observed between treatment groups for either the 6MWT or the 10MWT (detailed later); and brief description of the different treatment groups. The following symbols were used to indicate observed changes between groups: "+" indicates significant differences between groups; "O" indicates no significant differences between groups; and "…" indicates not tested. Points in the final column are based on the scoring system designed to evaluate the strength of the comparator intervention (see the "Methods" section). N/A in this column is used to indicate that the study was not given a point value or included in the determination of the strength of the recommendation because the experimental intervention was included in the comparator group (eg, compared eccentric with concentric strengthening).

APPENDIX TABLE 1. Walking Training at Moderate to High Aerobic Intensities

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
High-intensity versus stretching//passive exercise	Globas et al (2012)[75]; n = 38	1 (15)	CVA	+	+	TM, 60%-80% HRR, 3×/wk, 3 mo	Usual care physical therapy	2
	Gordon et al (2013)[76]; n = 128	1 (14)	CVA	+	…	OG walking, 60%-85% HR_{max}, 3×/wk, 12 wk	Light massage	1
	Luft et al (2008)[77]; n = 71	1 (13)	CVA	+	O	TM, 40 min, 60%-80% HR reserve, 3×/wk, 6 mo	Passive stretch	1
	Moore et al (2010)[24]; n = 20	1 (13)	CVA	O	O	Crossover: TM, 80%-85% HR_{max}, 2-5×/wk, 4 wk	Crossover: no intervention	0
	Macko et al (2005)[34]; n = 61	1 (12)	CVA	+	O	TM, 60%-80% HR reserve, 40 min, 3×/wk, 6 mo	Low intensity, 30%-40% HR reserve, stretch	2
Higher- versus lower-intensity walking training	Boyne et al (2016)[78]; n = 18	1 (18)	CVA	O	+	TM, HIIT (30 s max, <60 s rec) 3×/wk, 4 wk	TM, 45% HR reserve, 3×/wk, 4 wk	2
	Holleran et al (2015)[79]; n = 12	1 (12)	CVA	+	O	Crossover: TM & OG, 30 min, <80% HR reserve, 3×/wk, 4 wk	Crossover: TM & OG, 30 min, 30%-40% HRR, 3×/wk, 4 wk	2
	Ivey et al (2015)[80]; n = 34	1 (11)	CVA	O	O	TM, 30 min, 80%-85% HR reserve, 3×/wk, 6 mo	TM, 30 min, <50% HR reserve, 3×/wk, 6 mo	0
	Munari et al (2016)[81]; n = 16	1 (16)	CVA	+	+	TM-HITT (1 min 85% $\dot{V}o_2$peak, 3 min 50% $\dot{V}o_2$peak), 3×/wk, 3 mo	TM, 50-60 min, 40%-60% $\dot{V}o_2$ peak, 3×/wk, 3 mo	2
	Yang et al (2014)[82]; n = 22	1 (12)	SCI	+	O	Crossover: TM, 60 min, 5×/wk, 2 mo, faster than SSV	Crossover: precision training OG 5×/wk, 2 mo	2

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; HIIT, high-intensity interval training; HR, heart rate; HR_{max}, maximum heart rate; HRR, heart rate reserve; OG, over ground; SCI, spinal cord injury; SSV, self-selective velocity; TM, treadmill.

APPENDIX TABLE 2. Walking Training With Augmented Feedback/Virtual Reality

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
VR + walking + PT versus walking + PT	Cho and Lee (2013)[83]; n = 18	1 (12)	CVA	…	+	VR-community + TM, 30 min, 3×/wk, 6 wk + 30-min PT, 30-min FES, VR	TM, 30 min, 3×/wk, 6 wk + 30-min PT, 30-min FES	2
	Cho and Lee (2014)[84]; n = 50	1 (13)	CVA	…	+	VR-community + TM, 30 min, 3×/wk, 6 wk + 30-min PT, 30-min FES, VR	TM, 30 min, 3×/wk, 6 wk + 30-min OT, 30-min PT, 30-min FES	2
	Kang et al (2012)[85]; n = 16	1 (10)	CVA	+	+	VR + TM, 30 min, 3×/wk, 4 wk + PT. VR-path between trees	2 control groups: TM or stretch, 30 min, 3×/wk, 4 wk + PT	2
	Kim et al (2015)[86]; n = 74	2 (9)	CVA	…	+	VR +TM, 30 min, 3×/wk, 4 wk. VR-grocery shopping scenes	VR +TM, 30 min, 3×/wk, 4 wk.	2
	Yang et al (2008)[87]; n = 48	1 (11)	CVA	…	+	VR +TM, 20 min, 3×/wk, 3 wk. VR-community–based scenes	TM, 20 min, 3×/wk, 3 wk	2
VR TM walking versus other walking	Cho et al (2015)[88]; n = 45	1 (14)	CVA	…	O	VR + TM + cognitive, 30 min, 5×/wk, 4wk + 30-min PT	TM, 30 min, 5×/wk, 4 wk + 30-min PT	n/a
	Jaffe et al (2004)[89]; n = 16	2 (9)	CVA	O	+	VR + TM, 60 min, 3×/wk, 2 wk. VR-stepping over virtual objects	OG walking over obstacles, 60 min, 3×/wk, 2 wk	2
	Kim et al (2016)[90]; n = 24	2 (8)	CVA	O	…	VR + TM, 30 min, 3×/wk, 4 wk. VR-overground, uphill, obstacles	2 groups: usual PT or community 30 min, 3×/wk, 4 wk walking (outside, stairs, slopes, unstable surfaces)	0

Abbreviations: CVA, Cerebrovascular accident; FES, functional electrical stimulation; n/a, VR + TM in both groups, 1 with additional cognitive challenge; OG, over ground; OT, occupational therapy; PT, physical therapy; TM, treadmill; VR, virtual reality.

APPENDIX TABLE 3. Strength Training

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Strengthening versus no exercise	Flansbjer et al (2008)[91]; n = 24	1 (13)	CVA	O	O	2×6 to max reps 80% 1RM, 2×/wk, 10 wk	No intervention	0
	Severinsen et al (2014)[92]; n = 43	1 (14)	CVA	O	O	3 × 8 reps 80% 1RM, 3×/wk, 12 wk	2 groups—aerobic, 3×/wk, 12 wk or no intervention	0
	Yang et al (2006)[93]; n = 48	1 (14)	CVA	+	+	Functional strength exercises, 3×/wk, 1 mo	No intervention	1
Strengthening versus min exercise	Bourbonnais et al (2002)[94]; n = 26	1 (10)	CVA	+	+	Up to 70%-90%, reps incr, 3×/wk, 6 wk	Upper extremity exercise, 3×/wk, 6 wk	1
	Kim et al (2001)[95]; n = 20	1 (13)	CVA	…	O	3 × 10 reps max effort, 3×/wk, 6 wk	Passive LE ROM, 3×/wk, 6 wk	0
	Ouellette et al (2004)[96]; n = 42	1 (12)	CVA	O	O	3 × 10 reps 70% 1RM, 3×/wk, 12 wk	LE ROM, UE exercise, 3×/wk, 12 wk	0
Strength versus other exercise	Jayaraman et al (2013)[97]; n = 5	2 (9)	SCI	+	…	Crossover: 3 × 10 reps 100% 1RM. 3×/wk, 1 mo	Crossover: 3 × 12 reps, 60% 1RM, 3×/wk, 1 mo	2
	Kim et al (2016)[98]; n = 27	2 (9)	CVA	O	Oa	Strength 70% 1RM reps not listed, 5×/wk, 2 mo	Balance training, 5×/wk, 2 mo	0
	Labruyère R and van Hedel (2014)[99]; n = 9	1 (10)	SCI	…	+	Crossover 3 × 10-12 reps 70% 1RM, 4×/wk, 1 mo	Crossover: Lokomat, 4×/wk, 1 mo	2
Other	Clark and Patten (2013)[100]; n = 34	1 (14)	CVA	…	O	Eccentric strength training	Concentric strength training	n/a

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; LE, lower extremity; n/a, compared concentric to eccentric strengthening, both groups received strength training; 1RM, 1 repetition maximum; ROM, range of motion; SCI, spinal cord injury; UE, upper extremity.

[a]Comparison group was superior to experimental group.

APPENDIX TABLE 4. Cycling and Recumbent Stepping Training

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Cycling training	Bang and Son (2016)[101]; n = 12	2 (9)	CVA	+	+	Cycling, 50%-80% HR_{max}, 30 min, 5×/wk, 4 wk + conventional PT	Cycling, self-selected speed, 30 min, 5×/wk, 4 wk + conventional PT	2
	Jin et al (2012)[102]; n = 133	1 (10)	CVA	+	+	Cycling, 50%-70% HR reserve, 40 min, 5×/wk, 8 wk + balance and stretching	Cycling, 20%-30% HRR, 40 min, 5×/wk, 8 wk + balance/ stretching	2
	Jin et al (2013)[103]; n = 128	2 (9)	CVA	+	+	Cycling, 50%-70% HR reserve, 40 min, 5×/wk, 12 wk	Conventional PT, 40 min, 5×/wk, 12 wk	2
	Severinsen et al (2014)[92]; n = 43	1 (14)	CVA	O	O	Cycling, 75% HR reserve, 60 min, 3×/wk, 12 wk	2 groups: high-intensity LE strengthening or sham UE training, 60 min, 3×/wk, 12 wk	0
	Song and Park (2015)[104]; n = 40	2 (5)	CVA	…	O	Cycle ergometer, <40% HR reserve, 5×/wk, 2 mo	VR-X-box dynamic standing, 5× wk, 2 mo	0

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; HR_{max}, maximum heart rate; LE, lower extremity; PT, physical therapy; UE, upper extremity.

APPENDIX TABLE 5. Circuit and Combined Exercise Training

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Circuit training	Dean et al (2000)[105]; (n = 12	1 (10)	CVA	+	+	Balance, strength, walking, no intensity, 3×/wk, 1 mo	UE exercise class	1
	Moore et al (2016)[106]; n = 40	1 (16)	CVA	+	+	Balance, strength aerobic <80% HRR,3×/wk, 4 mo	No intervention	1
	Mudge et al (2009)[107]; n = 60	1 (16)	CVA	+	O	Balance, strength, walking, no intensity 3×/wk, 1 mo	No intervention	1
	Pang et al (2005)[108]; n = 63	1 (17)	CVA	+	…	Balance, strength aerobic <80% HRR; 3×/wk, 4 mo	UE intervention	1
	Song et al (2015)[109]; n = 30	2 (6)	CVA	+	+	Balance, strength no intensity; 5×/wk, 1 mo + PT	PT only	1
	Vahlberg et al (2016)[110]; n = 43	1 (12)	CVA	+	…	Balance/strength/walking/ cycling RPE <17, 2×/wk, 3 mo	No intervention	1
Combined training	Hui-Chan et al (2009)[111]; n = 109	1 (11)	CVA	…	+	Balance, strength, walking no intensity, 5×/wk, 1 mo	No intervention	1
	Lee et al (2015)[112]; n = 26	1 (10)	CVA	+	+	Strength, aerobic <70% HRR, 3×/wk, 4 mo	No intervention	1
	Tang et al (2014)[113]; n = 50	1 (10)	CVA	…	O	Balance, strength aerobic <80% HRR, 3×/wk, 6 mo	Balance, flexibility, low intensity, same schedule	0
	Teixeira-Salmela et al (1999)[114]; n = 13	2 (9)	CVA	…	+	Aerobic <70% HRR, strength <80% 1RMP, 3×/wk, 10 wk	Balance, flexibility, low intensity, same schedule	1

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; HRR, heart rate reserve; 1RM, 1 repetition maximum; PT, physical therapy; RPE, Ratings of Perceived Exertion; UE, upper extremity.

APPENDIX TABLE 6A. Balance Training: Sitting/Standing With Altered Feedback/Weight Shift

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Trunk stabilization	Dean and Shepherd (1997)[115]; (n=20)	1 (12)	CVA	…	O	Sitting/reaching > arm's length, 5×/wk, 2 wk	Sitting/reaching < arm's length, 5×/wk, 2 wk	0
	Kilinc et al (2016)[116]; n = 22	1 (12)	CVA	…	O	NDT/trunk exercises, 3×/wk, 3 mo	PT, 3×/wk, 3 mo	0
	Chun et al (2016)[117]; n = 28	2 (8)	CVA	…	O[a]	Lumbar stab. In standing, 3/wk, 7 wk	Standing training (Biodex), 3/wk, 7 wk	0
Standing weight shifting	Kim et al (2015)[118]; n = 22	2 (9)	CVA	…	+	Tai chi 2×/wk, + regular PT, 10×/wk, 6 wk	Regular PT, 10×/wk, 6 wk	1
	Aruin et al (2012)[119]; n = 18	2 (8)	CVA	…	O	Compelled weight shift during PT, 1×/wk, 6 wk	PT activities, 1×/wk, 6 wk	0
	Shiekh et al (2016)[120]; n = 28	1 (14)	CVA	…	O	Compelled weight shift during PT, 6×/wk, 6 wk	PT, 6×/wk, 6 wk	0
	You et al (2012)[121]; n = 27	2 (7)	CVA	…	O	Standing with device, limited parameters	Single-limb activities, limited parameters	0
Standing altered feedback	Bang et al (2014)[122]; n = 12	1 (10)	CVA	+	O	Balance w/unstable surface 30 min + 30 min TM, 5×/wk, 1 mo	30-min TM, 5×/wk, 1 mo	1
	Bayouk et al (2006)[123]; n = 16	1 (11)	CVA	…	O	Dynamic sit/standing with EC/foam, 2×/wk, 8 wk	Dynamic sit/standing, 2×/wk, 8 wk	0
	Bonan et al (2004)[124]; n = 20	1 (10)	CVA	…	O	Balance w/o vision + PT, 5×/wk, 1 mo	Balance with vision + PT, 5×/wk, 1 mo	0
	Kim et al (2016)[98]; n = 27	2 (8)	CVA	…	+	Biodex Balance System + PT, 5×/wk 2 mo	Strength training + PT, 5×/wk, 2 mo	2

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; EC, eyes closed; NDT, Neurodevelopmental treatment; PT, physical therapy; TM, treadmill.

[a]Authors indicate difference without direct comparisons of treatment groups.

APPENDIX TABLE 6B. Balance Training: Augmented Feedback With Vibration

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Balance with vibration	Brogårdh et al (2012)[125]; (n=31)	1 (17)	CVA	O	…	Platform 3.75 mm amp, freq: 25 Hz, standing, 2×/wk, 6 wk	Platform 0.2 mm, freq: 25 Hz, standing, 2×/wk, 6 wk	0
	Lau et al (2012)[126]; n = 82	1 (18)	CVA	O	O	Platform + dynamic LE exercise, 3×/wk, 8 wk	Dynamic LE exercise, 3×/wk, 8 wk	0
	Lee et al (2013)[127]; n = 31	1 (13)	CVA	…	+	Segmental vibration: 30’: dynamic standing balance + PT/FES, 5×/wk, 6 wk	Dynamic standing balance + PT/FES, 5×/wk, 6 wk	2
	Liao et al (2016)[128]; n = 31	1 (18)	CVA	O	O	Platform + dynamic LE exercise, 3×/wk, 8 wk	Dynamic LE exercise, 3×/wk, 8 wk	0

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; LE, lower extremity; PT, physical therapy; FES, functional electrical stimulation.

APPENDIX TABLE 6C. Balance Training: Augmented Visual Feedback

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
VR-balance + PT versus PT only	Kim et al (2009)[129]; n = 24	1 (13)	CVA	…	+	VR dynamic balance 4×/wk, 1 mo + PT 4×/wk, 1 mo	PT only, 4×/wk, 1 mo	1
	Lee et al (2014)[130]; n = 21	1 (14)	CVA	…	+	Augmented visual input during postural training (sit/stand); 3×/wk, 1 mo + PT, 5×/wk, 1 mo	PT only, 5×/wk, 1 mo	1
	Park et al (2013)[131]; n = 16	1 (10)	CVA	…	O	VR supine, sit, stand, 3×/wk, 1 mo + PT 5×/wk, 1 mo	PT only, 5×/wk, 1 mo	0
	Yom et al (2015)[132]; n = 20	2 (5)	CVA	…	+	Standing ankle exercise with VR; 5×/wk, 6 wk, 30-min sessions; + conventional PT	Watched documentary; 5×/wk, 6 wk, 30-min sessions; + b conventional PT	1
VR–balance versus balance or other	Chung et al (2014)[133]; n = 19	2 (9)	CVA	…	+	Core stabilization with VR, 5×/wk, 6 wk	Core stabilization without VR, 5×/wk, 6 wk	2
	Gil-Gomez et al (2011)[134]; n = 17	1 (10)	TBI, CVA	O	O	Wii sitting and dynamic standing, 20 sessions	PT—balance activities, 20 sessions	0
	Llorens et al (2015)[135]; n = 20	1 (12)	CVA	…	+	30-min VR dynamic standing + PT, 5×/wk, 20 sessions	PT standing, stepping, walking, 5×/wk, 20 sessions	1
	Song and Park (2015)[104]; n = 40	2 (5)	CVA	…	O	VR-X-box dynamic standing, 5×/wk, 2 mo	Cycle ergometer, <40% HR reserve, 5× wk, 2 mo	0
Other	Fritz et al (2013)[136]; n = 30	1 (15)	CVA	O	O	Wii + standing balance training, no supervision, 5×/wk, 1 mo	No intervention	0

Abbreviations: CVA, Cerebrovascular accident; Dx, diagnosis; PT, physical therapy; TBI, traumatic brain injury; VR, virtual reality.

APPENDIX TABLE 7. Body Weight–Supported Treadmill Walking

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
BWSTT versus other walking exercise	Alexeeva et al (2011)[137]; n = 35	1 (12)	SCI	…	O	TM, 30%BWS, 3×/wk, 60 min, 13 wk, SSV	2 groups—conventional PT and OG BWS training, 3×/wk, 60 min, 13 wk, 30%BWS, SSV	0
	Brown et al (2005)[138]; n = 20	2 (7)	TBI	O	O	TM, 30%BWS, 2×/wk, 14 wk + 30-min exercise, 1-3 PT asst kinematics	OG, 2×/wk, 14 wk + 30-min exercise	0
	Combs-Miller (2014)[36]; n = 20	1 (15)	CVA	O	O[a]	TM, 30%BWS, 5×/wk, 2 wk, PT asst kinematics	OG walking, 5×/wk, 2 wk, walk fast, ≤ moderate intensity	0
	Middleton et al (2014)[139]; n = 43	1 (11)	CVA	O	O	TM, 30%BWS, 60 min, 10 d, PT asst + 2-h balance, strength, ROM, coordination	OG walking, 60 min, 10 d, + 2-h balance, strength, ROM, coordination	0
	Suputtitada et al (2004)[140]; n = 48	2 (7)	CVA	…	O	TM, 30% BWS decr, 5×/wk, 4 wk, 0.44 m/s, increased as tolerated, 2 PT assist	OG walking, 15 min, 5×/wk, 4 wk	0
BWSTT versus conventional PT	Lucarelli et al (2011)[141]; n = 30	2 (7)	SCI	…	O[b]	TM, 40% BWS decr, 2×/wk, 30 sessions, SSV, 2 PT asst kinematics + strength/ROM	OG walking, 2×/wk, 30 sessions, SSV, + stretching/ROM	0
	Ribeiro et al (2013)[142]; n = 23	1 (10)	CVA	…	O	TM, 30% BWS/PT assist kinematics as needed, 3×/wk, 4 wk, SSV	PNF, 3×/wk, 30 min, 4 wk	0
	Yen et al (2008)[143]; n = 14	1 (10)	CVA	…	+	TM,<40% BWS, 3×/wk, 4 wk, asst kinematics, +2-5×/wk general PT	2-5×/wk general PT	1
BWSTT versus no PT/other	Takao et al (2015)[144]; n = 18	1 (11)	CVA	…	+	TM, 20% BWS, 3×/wk, 4 wk, fastest possible speed	No intervention	1
	Sullivan et al (2002)[32]; n = 24	1 (11)	CVA	…	O	TM, 40% BWS, 2.0 mph, 20 min × 12 sessions, 4-5 wk	TM, 40% BWS, 0.5/5-2.0 mph, 20 min × 12 sessions, 4-5 wk	n/a

Abbreviations: BWS, body weight support; BWSTT, body weight–supported treadmill training; Dx, diagnosis; n/a, compared speeds, both groups with BWS; OG, over ground; PNF, proprioceptive neuromuscular facilitation; PT, physical therapy; ROM, range of motion; SCI, spinal cord injury; SSV, self-selected velocity; TBI, traumatic brain injury; TM, treadmill.

[a]Results favored the control (comparison) condition.

[b]Authors indicate difference without direct comparisons of treatment groups.

APPENDIX TABLE 8. Robotic-Assisted Walking Training

	ARTICLE (SAMPLE SIZE)	LEVEL (TALLY)	DX	TIMED DISTANCE	GAIT SPEED	EXPERIMENTAL	CONTROL	POINTS
Robotics versus walking alone	Bang and Shin (2016)[145]; n = 18	1 (11)	CVA	…	+	Lokomat 45% BWS, 60 min, 5×/wk, 4 wk, > 0.45 m/s	TM, no BWS, 60 min, 5×/wk, 4 wk, speed incr 10%/session	2
	Buesing et al (2015)[146]; n = 50	1 (14)	CVA	…	O	OG with hip assist, 45 min, 3×/wk, 6-8 wk, 75% HR_{max}	OG, 45 min, 3×/wk, <8 wk, variable walking, 75% HR_{max}	0
	Esquenazi et al (2013)[147]; n = 16	2 (9)	TBI	O	O	Lokomat, 10%-20% BWS, 45 min, 3×/wk, 6 wk	TM, 10%-20% BWS, PT assist, 45 min, 3×/wk, 6 wk	0
	Field-Fote and Roach (2011)[148]; n = 74	1 (12)	SCI	O[a]	O	Lokomat, <30% BWS, 5×/wk, 12 wk, goal of 13 on RPE scale	TM <30% BWS or OG + e-stim or TM + e-stim, 5×/wk, 12 wk	0
	Hornby et al (2008)[37]; n = 48	1 (13)	CVA	O	O[a]	Lokomat, <30%-40% BWS, 30 min, 3×/wk, 4 wk	<30%-40% BWS, PT assist as needed, 30 min, 3×/wk, 4 wk	0
	Peurala et al (2005)[149]; n = 45	1 (11)	CVA	O	O	Gait trainer, 20% BWS, 20 min, 5×/wk, 4 wk + regular PT	2 groups: robot + FES, OG; 20 min, 5×/wk, 4 wk + regular PT	0
	Westlake and Patten (2009)[150]; n = 16	1 (14)	CVA	O	O	Lokomat, 35% BWS, (<0.69, >0.83 m/s, 30 min, 3×/wk, 4 wk	BWSTT, 35%BWS, 30 min, 3×/wk, 4 wk	0
Robotics versus PT	Stein et al (2014)[151]; n = 24	1 (14)	CVA	O	O	Powered knee orthosis during walking, 50 min, 3×/wk, 6 wk	Group exercise, stretch light walking, matched duration	0
	Ucar et al (2014)[152]; n = 22	2 (9)	CVA	…	+	Lokomat, 50% BWS, 30 min, 5×/wk, 2 wk	ROM, strength, balance, gait, 30 min, 5×/wk, 2 wk	2
Robotics versus other	Forrester et al (2016)[153]; n = 26	2 (9)	CVA	…	O	Ankle robot during TM, 60 min, 3×/wk, 6 wk	Seated ankle robot exercises, 60 min, 3×/wk, 6 wk	0
	Labruyère and van Hedel (2014)[99]; n = 9	1 (10)	SCI	…	O[a]	Lokomat, 30% BWS, 45 min, 4×/wk, 4 wk	Lower extremity strengthening, 45 min, 4×/wk, 4 wk	0
Robot assist versus resist	Lam et al (2015)[154]; n = 15	1 (15)	SCI	O	O	Lokomat with resistance, BWS, 45 min, 3×/wk, 3 mo	Lokomat with assistance, BWS, 45 min, 3×/wk, 3 mo	n/a
	Wu et al (2014)[155]; n = 30	2 (9)	CVA	O	O	Cable swing resist w/TM, 45 min, 3×/wk, 6 wk	Cable swing assist w/TM, 45 min, 3×/wk, 6 wk	n/a
	Wu et al (2016)[156]; n = 14	1 (12)	SCI	O	O	Cable swing resist w/TM, 45 min, 3×/wk, 6 wk	Cable swing assist w/TM, 45 min, 3×/wk, 6 wk	n/a
	Wu et al (2012)[157]; n = 10	2 (9)	SCI	O	O	Cable swing resistance during TM, 45 min, 3×/wk, 4 wk	Cable swing assist during TM, 45 min, 3×/wk, 4 wk	n/a

Abbreviations: BWS, body weight support; BWSTT, body weight–supported treadmill training; CVA, Cerebrovascular accident; Dx, diganosis; FES, functional electrical stimulation; HR_{max}, maximum heart rate; n/a, compared robotic assistance versus robotic resistance, robotics in both groups; OG, over ground; PT, physical therapy; RPE, Ratings of Perceived Exertion; SCI, spinal cord injury; TM, treadmill; TBI, traumatic brain injury.

[a]Results favored the control (comparison) condition.

