Clinical practice guideline to improve locomotor function following chronic stroke, incomplete spinal cord injury and brain injury

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

**Background:** Individuals with stroke, motor incomplete spinal cord injury (iSCI) or traumatic brain injury (TBI) often experience lasting locomotor deficits, as quantified by decreases in gait speed and timed walking distance. The goal of the present Clinical Practice Guideline (CPG) was to delineate the relative efficacy of various interventions to improve walking speed and timed distance in individuals > 6 months following these specific diagnoses. **Methods:** A systematic review of the literature published between 1995-2016 was performed in 4 databases for randomized controlled clinical trials (RCTs) focused on these specific patient populations, at least 6 months post-injury 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 based on 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 (VR)-based training to individuals with stroke, iSCI, and TBI to improve walking speed or distance. In contrast, weak evidence suggests that strength training, circuit (i.e., combined) training or cycling training at moderate to high intensities, and VR-based balance training may improve walking speed and distance. Finally, strong evidence suggests body-weight supported treadmill training, robotic-assisted training, or sitting/standing balance training without VR should not be performed to improve walking speed or distance. **Summary:** The guideline suggests task-specific walking training should be performed, although only at higher intensities or with augmented feedback, as non-specific or reduced intensity interventions did not consistently result in positive outcomes. 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, iSCI, and TBI to improve walking speed and distance.
## Table of Contents

Summary of Action Statements ............................................................................................................... 7

*Overview and Justification* .................................................................................................................. 11

*Scope and rationale* ............................................................................................................................. 15

*Target audience* ....................................................................................................................................... 17

*Statement of Intent* .................................................................................................................................. 18

**Methods** ................................................................................................................................................. 20

*Literature search* ..................................................................................................................................... 21

*Screening articles* ..................................................................................................................................... 23

*Article appraisal* ..................................................................................................................................... 24

*Formulating recommendations* .............................................................................................................. 25

*Patient views and preferences* .................................................................................................................. 30

*Expert and Stakeholder Review* ............................................................................................................... 30

*Knowledge Translation and Implementation Plan* .................................................................................. 31

*Update and Revision of Guidelines* ......................................................................................................... 31

**Action Statements and Research Recommendations** ........................................................................... 33

*Summary and Clinical Implementation* .................................................................................................... 95

*Influence of training parameters on locomotor performance* .................................................................. 95

*Clinical implications* ............................................................................................................................... 97

*Implementation recommendations* ......................................................................................................... 99

*Limitations and future recommendations* ............................................................................................... 102

*Conclusions* ............................................................................................................................................. 103

*Summary of Research Recommendations* .............................................................................................. 104

*References* ............................................................................................................................................... 107

*Tables and Figures* ................................................................................................................................. 121

*Table 1. Example of PICO Search Terms for strength training* ................................................................. 121

*Table 2. Survey results.* .............................................................................................................................. 122

*Table 3. Grading Levels of Evidence* ........................................................................................................ 123

*Table 4. Standard Definitions for Recommendations* ............................................................................... 124

*Table 5. Recommendation criteria for CPG on Locomotor Function* ...................................................... 125

*Table 6. Final recommendations for CPG on Locomotor Function* .......................................................... 126

*Figure. Flow chart for article searches and appraisals* .............................................................................. 127
Summary of Action Statements

**Action Statement 1:** EFFECTIVENESS OF STRENGTH TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES OF AN ACUTE-ONSET CNS INJURY. Clinicians may consider providing strength training to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: weak)

**Action Statement 2:** EFFECTIVENESS OF BALANCE TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. (A) 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 with acute-onset CNS injury. (B) Clinicians should not use sitting or standing balance training with additional vibratory stimuli to improve walking speed and distance in individuals with acute-onset CNS injury. (C) Clinicians may consider use of static and dynamic (non-walking) balance strategies when coupled with virtual reality or augmented visual feedback to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong)

**Action Statement 3:** EFFECTIVENESS OF CYCLING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians may consider use of cycling or recumbent stepping interventions instead of alternative interventions to improve walking speed and distance in individuals in the chronic stages following an acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: weak).
**Action Statement 4:** EFFECTIVENESS OF CIRCUIT TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians may consider use of circuit training or combined strategies providing balance, strength, and aerobic exercises to improve walking speed and distance in individuals with acute-onset CNS injury as compared to alternative interventions. (Evidence quality: I-II; recommendation strength: weak).

**Action Statement 5:** EFFECTIVENESS OF MODERATE TO HIGH INTENSITY WALKING TRAINING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should use moderate to high intensity walking training interventions to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement 6:** EFFECTIVENESS OF BODY WEIGHT SUPPORTED TREADMILL TRAINING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES OF AN ACUTE-ONSET CNS INJURY. Clinicians should not perform body weight supported treadmill training versus over-ground walking training or conventional training for improving walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement 7:** EFFECTIVENESS OF ROBOTIC-ASSISTED WALKING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should not perform
walking interventions with robotics to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement 8:** EFFECTIVENESS OF VIRTUAL REALITY WALKING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should use virtual reality training interventions coupled with walking practice for improving walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).
Introduction

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 in an effort 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 objective of this clinical practice guideline (CPG) is to provide concise recommendations detailing the efficacy of exercise interventions utilized to improve walking speed and timed distance in individuals > 6 months following an acute-onset, central nervous system (CNS) injury. These diagnoses include individuals post-stroke, motor incomplete spinal cord injury (iSCI) and traumatic brain injury (TBI), during which the initial neurological insult occurs suddenly, as opposed to progressive degenerative neurological disorders. While published systematic reviews, meta-analyses, and other CPGs have described the potential efficacy of various rehabilitation interventions for these diagnoses1-5, their clinical utility and effectiveness towards facilitating changes in clinical practice is not certain. More directly, available data indicate clinical practice patterns to improve walking function in these patient populations are not consistent with established training parameters known to enhance motor skill and function6-13. While reasons underlying the lack of translation of current evidence into clinical practice are multifactorial, the goal of this CPG is to detail the relative efficacy of specific interventions to
improve locomotor function, and employ a theoretical framework that may facilitate implementation of the recommended strategies.

The proposed CPG will delineate evidence of strategies that improve locomotor function, as evaluated by changes in gait speed or timed walking distance, with specific details of the rehabilitation interventions provided. These details will be organized within the context of guiding exercise training principles that can facilitate neuromuscular and cardiovascular changes to improve walking performance\textsuperscript{14,15}. To our knowledge, this approach towards CPG development 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, which include modifiable training parameters of type, amount (duration and frequency) and intensity of practice, are given only brief mention, but are important determinants of the efficacy of these interventions\textsuperscript{16,17}. Providing such analyses in a CPG will equip clinicians with a better understanding of the rationale and evidence underlying specific interventions and provide comprehensive details of training parameters to facilitate their implementation.

\textbf{Overview and Justification}

The incidence and prevalence of acute-onset neurological diseases, including stroke, iSCI, or TBI have increased substantially in the past decades. For example, the incidence of stroke in the US has reached nearly 800,000 per year with a prevalence of 4-5 million, most of whom experience mobility deficits\textsuperscript{18,19}. For SCI, approximately 17,000 new cases present each year, with the prevalence of approximately 300,000 in the US alone\textsuperscript{20} . Of this population, about 50-60\% have 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. Given the importance of physical activity and mobility on neuromuscular, cardiovascular and metabolic function, as well as on community participation, effective strategies to improve walking function in these patients will be critical with an aging population.

The available literature suggests an extraordinary number of interventions have been designed to improve walking function in these populations. Many studies have demonstrated some level of efficacy for specific techniques, including neurofacilitation, strategies that focus on specific impairments in body structure/function (weakness, balance, or endurance deficits) or combined interventions, and training paradigms delivering more task-specific practice, including upright walking. During walking training interventions, the stepping tasks practiced can also vary substantially. Many studies have delineated the effects of walking with or without physical assistance from therapists, with or without body weight support on a motorized treadmill, walking overground, stepping with robotic assistance with treadmills or elliptical devices, or walking while performing variable stepping tasks (multiple walking tasks or environments). The amount of research detailing various exercise interventions in these populations may be overwhelming; a brief literature search reveals thousands of studies recruiting individuals post-stroke have focused on improving walking recovery. For a clinician, attempting to sort through these studies to identify the most clinically feasible and effective intervention may be difficult, if not impossible.

Meta-analyses detailing the cumulative efficacy for a particular diagnosis have been of great value to clinicians and researchers. For example, recent Cochrane reviews synthesizing available literature on treadmill training or robotic-assisted walking training collectively reviewed ~450 articles to detail the relative efficacy of these interventions over alternative
strategies. Similar meta-analyses are available for locomotor training in iSCI\textsuperscript{41} and for overground walking post-stroke\textsuperscript{42}, with less data available for TBI. The utility of these reviews are their ability to condense data from multiple studies, with a primary goal to provide an estimated effect size for comparison to other interventions.

While valuable, the potential problems with these reviews are highlighted by a few key issues. A primary concern is the combination of data from multiple studies evaluating a specific intervention as compared to another comparison (or control) group. When defining the experimental or control interventions, specific parameters regarding the type, amount and intensity (i.e., cardiopulmonary demands) are often not accounted for, nor detailed, in published studies. However, these variables may strongly influence the efficacy of exercise strategies. One example is the use of treadmill walking, and studies utilizing this strategy vary substantially in the total number, frequency or duration of sessions, all of which can affect the amount of practice\textsuperscript{32,35}. Further, selected studies focus on varying speeds, while others provide body weight support with physical assistance at the limbs, both of which can influence the cardiopulmonary (i.e., metabolic) demands. Oftentimes such interventions are provided in addition to conventional therapy, which is seldom described in detail\textsuperscript{43}, and these comparison or control groups also demonstrate significant variability. Specifically, some studies compare an experimental intervention to usual care\textsuperscript{25,27}, which may consist of no or very limited interventions, or another strategy that may vary in the type, amount or difficulty of practice provided. Consolidation of these data into meta-analyses may exaggerate or dilute the potential strength of any specific intervention by masking details of training that are critical for improving outcomes.

These additional training variables that may influence study outcomes are consistent with parameters of exercise “dose”, which have long been speculated to impact locomotor recovery in
individuals with neurological injury. More directly, there are clear data in animal models and individuals with and without neurological injury that the specificity, amount and intensity of practice are significant determinants of changes in motor function, and in neuromuscular and cardiopulmonary adaptations sub-serving improved task performance\textsuperscript{16,17}. These three parameters are consistent with the FITT principle\textsuperscript{15,44} (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 may reflect the amount of practice provided if specific repetitions of an exercise are not detailed. “Type” of exercise is consistent with the specific exercise performed. Finally, “intensity” is defined as power output or rate of work (i.e., workload), consistent with the exercise physiology literature, and is manipulated by altering the loads carried or speeds of tasks. In strength training studies, intensity is estimated using the loads lifted and defined as a percentage of a person’s maximum load lifted for 1 repetition (1 rep max or RM), whereas HRs are often utilized during exercise performance over sustained durations. Organizing a CPG around these parameters may 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 Center for Medicare and Medicaid Services (CMS), along with commercial payers of health care services, are actively seeking strategies to reduce the costs and variability in post-acute care\textsuperscript{45}. Programs such as the Bundled Payments for Care Improvement (BPCI) Initiative are examples of bundling reimbursement for acute and post-acute 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\textsuperscript{46}. In addition, CMS is shifting to new models defining reimbursement for skilled nursing and home care to that remove rehabilitation utilization as the primary driver of reimbursement and replace it with models defined by patient characteristics and assessments\textsuperscript{47,48}. Further, 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 limitation 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.

\textit{Scope and rationale}

The overarching theme of this CPG is that the efficacy of specific physical interventions applied to individuals with acute-onset CNS injury are largely determined by the training parameters applied during treatment. These factors, as well as 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 \textit{a priori}, with the rationale discussed below.

\textit{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 (> 18 years age) of both genders, and includes all races and ethnicities. Consistent with conventional definitions, we defined “chronic” injury as more than 6 months following the initial injury, following which time the extent of spontaneous neurological recovery is limited\textsuperscript{49,50}. Focus only on individuals in the chronic stages post-injury mitigates much of the variability of motor return observed during the subacute stages of recovery.
(e.g., < 6 months post-injury)51. Such variability can obscure the potential benefit of specific interventions, particularly in underpowered studies. The interventions 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 three diagnoses has been articulated in recent editorials52 and research studies53. While the clinical presentation of these patients can vary, all represent acute-onset (e.g., non-progressive) 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. Further, a fundamental tenet used to support the incorporation of all three diagnoses in this CPG is that principles underlying plastic changes along the neuraxis are consistent across individuals with different health conditions14. Specifically, changes in motor function following neurological injury may be due more to the similar neuroplastic mechanisms in spared neural pathways, or adaptations in cardiovascular or muscular function, as opposed to separate mechanisms observed in discrete diagnoses52.

Selection of outcomes. The primary outcomes utilized in this CPG are related to walking function, which are strongly associated with strength, balance, peak fitness, falls and balance confidence54-56, as well as selected measures of quality of life, participation and mortality57,58. In this CPG, we are specifically utilizing measures of walking speed over shorter distances, and total distance walked over a sustained duration. The primary measures of interest therefore include walking speed, using either the 10 m walk test (10MWT) or similar walking speed
evaluations assessed over short distances, and timed walking distance, including the 6 min walk test (6MWT), but can also include the 2 or 12 min walk tests. These measures of walking speed and distance have been recently recommended by the CPG of outcome measures to be used in neurological rehabilitation\textsuperscript{59}, and have demonstrated strong reliability, validity and predictive value for fall risk and mortality. Accordingly, use of these specific outcome measures may limit the participant populations to those who are able to walk for abbreviated distances (e.g., 10 m) and may exclude research studies utilizing primarily non-ambulatory participants.

\textit{Selection of evidence.} In selecting specific studies for inclusion, we have focused our attention on only randomized controlled clinical trials (RCTs) with a primary or secondary goal to improve walking function in the selected patient populations. While many non-controlled 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 to 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. Accordingly, only RCTs were considered in the present analyses to minimize bias, potential testing effects or increased attention.

\textit{Target audience}

The present CPG should be useful to many rehabilitation professionals, but will target primarily those therapists, physicians and nurses who treat individuals with these specific 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 strongly 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. The CPG will likely also be of value to regulatory bodies and policy makers, professional associations (e.g., APTA, ANPT) and third party payers.

Statement of Intent

This guideline is intended for clinicians, patients and their family members, educators, researchers, administrators, policy makers and payers. With additional research in the field of rehabilitation, the ongoing development of this guideline will provide a synthesis of current research and recommended actions under specific conditions, with improved knowledge with new evidence, 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 locomotor function followed a formal process and rigorous methodology to ensure completeness, 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 and the Institute of Medicine (IOM).

The Guideline Development Group (GDG) was comprised of 4 core members, all of whom were physical therapists with clinical experience in treating individuals with acute and chronic CNS injury. The Administrative Chair (TGH) and Research Content Expert (DSR) were both faculty within physical therapy/physical medicine and rehabilitation departments within 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 (PLS) was a clinician, administrator and educator within inpatient, home health, and outpatient settings. She is currently a corporate clinical leader overseeing knowledge translation efforts across a moderately sized (>200 site) post-acute therapy provider. The CPG methodologist (IGW) was a clinical practice leader at her local hospital system and currently a research coordinator for center projects for individuals with TBI. She received standardized training for CPG development through the APTA Department of Practice. Members of the GDG proposed the topic to the APTA and ANPT and attended the APTA Workshop on Development of Clinical Practice Guidelines in 2014. The GDG held 5-6 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, two additional physical therapists (AM and DH) were included to the GDG to
assist with data extraction and database management. Two medical librarians also contributed to
this project; one librarian completed all the literature searches to ensure consistency, while the
other assisted with locating full-text articles.

**Literature search**

A two-step process for performing literature searches was adopted. A broad search was first
conducted to ensure 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. Additionally, the National Guidelines Clearinghouse,
Guidelines International Network, and standard electronic databases (i.e. 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. Further, the GDG wished to
refine the scope of the CPG by clearly identifying PICO questions (patient, intervention,
control/comparison, and outcomes as detailed above in Introduction) and relevant conceptual
definitions for the proposed CPG. Secondary literature searches were conducted using more
specific inclusion and exclusion criteria in pre-specified databases, with a goal to obtain all
RCTs published between January 1995-December 2016. Systematic reviews relevant to
interventions that may improve walking function in individuals with acute-onset neurological
injury 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 (please see Fig 1), 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 1, 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 to be considered, a survey on practice preferences was used to collect information on treatment strategies used by physical therapists and physical therapist assistants in the US. 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 PTs and 2 PTAs, in addition to clinicians’ practice preferences related to locomotor training. Approximately half (45%) of respondents were practicing therapists for > 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 two most commonly used standard tests for measuring walking function reported was the 10MWT (83%) and the 6MWT (80%). Approximately half of the respondents (49%) spend 50-75% 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 2, indicating 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 intervention representative of the current literature.

Search terms were created using these or associated terminology (e.g., 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. While FES is certainly utilized in specific research protocols\cite{phantom}, the use of FES is also often considered a type of orthosis used to assist with ankle dorsiflexion and eversion\cite{phantom1,phantom2,phantom3}, and a separate ANPT/APTA-sponsored CPG for use of prosthetics and orthotics is in development. Aquatic therapy was also not incorporated due to the low frequency of use (Table 2) and the inability to combine this intervention with other strategies.

**Screening articles**

All articles returned from each search were screened to ensure they met criteria. Two members of the GDG with content expertise (TGH, DSR) 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 two other GDG members (IGW, PLS) 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 > 6 months post-injury; 2) one outcome measure of gait speed or timed distance; 3) article addresses 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 on-line in 2016); and, 6) written in English language. An additional criterion was that all articles must involve more than one exercise session to qualify as a training study. When required, authors of articles were contacted to confirm specific information necessary for inclusion (e.g., duration post-injury).
Article appraisal

The APTA Critical Appraisal Tool for Experimental Interventions (CAT-EI) was used to appraise relevant articles. The CAT-EI is comprised of three sections (Parts A-C): part A detailed general article information (e.g., 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, 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, where ≥10 points indicated a Level 1 study and <10 points indicated a Level 2 study. 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 on-line training video created by the APTA CPG Development Group. Each appraiser completed a practice appraisal on a sample article, and subsequently reviewed two separate articles as “test” conditions, where scores on Part B of the CAT-EI were within 2 points (i.e., 10%) of the final score. Eight appraisers (four researchers and four clinicians) successfully completed training and participated in guideline development. Appraisers were paired based on primary employment responsibilities (one researcher to one 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.

**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 level of evidence, appraisal score, participant diagnoses, sample size, primary walking related outcomes, and details regarding the intervention and the control group (including details of FITT as available; please see Appendix Tables 1-8). Articles within evidence tables were subcategorized depending upon the available evidence and specific experimental or control interventions. For example, strength training articles were subcategorized based on variations between the comparison groups described in each study, including those studies that provided no intervention, limited lower extremity activities (i.e., 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 (i.e., “virtual reality”) 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. Each action statement includes the following elements: strength of recommendation, aggregate evidence quality, benefit-harm assessment, value judgements,
intentional vagueness, role of patient/caregiver preferences, exclusions, quality improvement, implementation and audit. 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 IOM. Recommendations for each intervention strategy 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 included “strong” (A), “moderate” (B), and “weak” (C), as well as separate theoretical/foundational (D), best practice (P), and research recommendations (R). Only A-C recommendations were provided, and theoretical/foundational premises or best practice recommendations were not utilized to minimize subjective bias. A recommendation of A-C was determined by the quality of articles, magnitude of benefit vs harm and level of certainty as described below.

Quality of research articles: Only RCTs were included in this CPG, and all articles were rated as Level 1 or 2, and considered high quality using available recommendations (i.e., RCTs, Table 3-4).

Magnitude of benefit vs 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 as the number (i.e., percentage) of articles that demonstrated a significant benefit as compared to a comparison group, as described below 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.

The cost of delivering the intervention was also considered, which could include the cost of equipment necessary for the training (e.g., treadmills, robotic systems, virtual reality systems) or to monitor safety (e.g., 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 (e.g., therapist time) and the time and travel necessary to receive a specific intervention. These latter costs were relevant as provision of an intervention that did not improve walking may be considered a misuse of resources, particularly as such costs may have been utilized to provide another, potentially more efficacious intervention. The standardized terminology typically utilized in CPG development to indicate magnitude of harm, risk, or benefit is detailed in Table 4.

Degree of certainty: To determine the level of certainty, the details of the experimental and comparison interventions were evaluated. While a portion of the articles reviewed could be synthesized into meta-analyses, many studies lacked sufficient detail regarding the effect sizes or the estimates of precision of changes in walking function. Further, substantial heterogeneity of selected interventions were described throughout the studies, particularly in the comparison (i.e.,
control) conditions, which may affect the “dose” of exercise provided. Rather, the current CPG weighed the consistency of observed benefits for a specific experimental intervention and the types of comparison (control) interventions described to determine the level of certainty and strength of a recommendation.

To evaluate the consistency of results for a specific experimental intervention, we determined the ratio of number of studies that demonstrated significantly greater gains in walking speed or timed distance using the experimental intervention as compared to the total number of studies for that intervention. To evaluate the control interventions, we detailed the types and amounts of exercises provided in the comparison strategies. More directly, a large proportion of the studies often compared an experimental strategy to an active comparison group that received an equal duration of therapy targeting the lower extremities or trunk. These alternative strategies were considered consistent with potential interventions used clinically to improve locomotor function. Conversely, use of comparison interventions that did not provide an equivalent amount of therapy, or provided interventions that would not reasonably be expected to improve locomotor function (e.g. upper extremity or cognitive tasks), were not consistent with those utilized in the clinical setting to address walking deficits. For studies detailing a given experimental intervention, if the majority of articles compared this intervention to alternative strategies that would not typically be utilized or expected to address locomotor dysfunction, then the degree of certainty that an experimental intervention could be beneficial was reduced. Both the consistency of positive outcomes for experimental interventions and the quality of the comparison intervention contributed to the strength of the recommendation (i.e., strong, moderate or weak).

The strength of the recommendation informed the level of obligation and specific terminology utilized to formulate the action statement, as described in Table 5. A “strong” or
“moderate” recommendation, designated as a high to moderate degree of certainty of benefit, resulted in a “should” recommendation. To minimize subjectivity of recommendations, the consensus of the GDG was that at least 67% (i.e., two-thirds) of the available articles for a given intervention would indicate a positive effect on either walking speed or distance as compared to an equal amount of conventional or other strategies. Conversely, a “strong” or “moderate” recommendation that clinicians “should not” provide an intervention was indicated if at least 67% of the available research suggest worse of no difference in outcomes between an equal duration of experimental vs control interventions. A “should not” recommendation indicated a preponderance of harm, risk, or cost were associated with the experimental interventions, given no superiority over a range of comparison interventions, particularly when other, more effective interventions were not utilized. Differentiation of “strong” vs “moderate” recommendations (A or B) were made based on the percentage of Level 1 articles; “strong” recommendations were provided with ≥ 50% Level 1 articles, whereas “moderate” was < 50% Level 1 articles (Table 5).

To assign a “weak” recommendation for a given intervention, the GDG considered 33-67% of articles should indicate a positive effect of the experimental intervention as compared to an equal duration of conventional or alternative therapy. 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. In addition, a “weak” recommendation was also assigned if the experimental intervention was consistently better (i.e., > 67% of articles) than a comparison intervention consisting of no treatment, unequal duration of therapy or attention, or if the control intervention likely would not improve locomotor function (e.g., upper extremity or cognitive tasks).
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. This criterion was developed to reduce the likelihood a recommendation would change substantially during revision based on a single article.

**Patient views and preferences.**

Patient views and preferences for both outcomes and interventions were identified through recent literature detailing perspectives from individuals who have received physical rehabilitation following CNS injury. Specific preferences for outcomes included faster walking speeds and walking for longer distances, which is consistent with the importance of locomotor function to health and mortality. Specific preferences of therapy sessions identified from the literature included shorter durations of therapy (20-60 minutes vs up to 6 hours) and activities performed at lower to moderate intensities. Selected literature suggests more traditional rehabilitation regimens could be preferred, although the attraction of technology and devices to assist rehabilitation have facilitated greater use of many robotic or technologically advanced systems during rehabilitation of these patient populations. Finally, patients’ perspectives may vary with the potential benefits gained, in that specific preferences can change depending on the extent of walking improvement realized. 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, administrators, educators and physicians) and the Evidence Based Document Committee of the Academy of Neurologic
Physical Therapy. Reviewers were invited to participate in the review process. The expert panel included 6 researchers with expertise in postural control and balance training, strength training, rehabilitation robotics, virtual reality, 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 website for public comment and followed similar process described above prior to submission for publication.

**Knowledge Translation and Implementation Plan.**

General recommendations for implementation are provided with each recommendation with potential factors that may influence implementation provided in Summary. 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.

**Update and Revision of Guidelines.**
This guideline will be updated and revised within 5 years of its publication, or sooner, as new evidence becomes available. The procedures for updated the guideline will be similar to those used here, with updated procedures based on recommended standards, and sponsored by the APTA/ANPT. Any updates to the guideline in the interim period will be posted on the ANPT website: neuropt.org.
**Action Statements and Research Recommendations**

**Action Statement 1:** EFFECTIVENESS OF STRENGTH TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES OF AN ACUTE-ONSET CNS INJURY. Clinicians may consider providing strength training to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: weak)

**Aggregate evidence quality:** Level 1. Based on eight Level 1 and two Level 2 RCTs examining whether strength training interventions are more beneficial than no interventions or other physical interventions. In 3 Level 1 studies comparing strength training to no intervention, 2 studies showed no positive effects on walking outcomes, while one study demonstrated significantly greater gains in walking function. In 3 studies comparing strength training to conventional lower and upper extremity interventions, 1 study showed a benefit on walking outcomes, while 2 studies showed no difference. Comparison of strength training to other lower extremity exercises revealed 2 studies that demonstrated beneficial effects of strength training whereas one study showed worse outcomes. A final study that compared eccentric to concentric strength training demonstrated no superiority of either intervention on walking outcomes. In total, 4 of 9 studies comparing strengthening exercises to other interventions revealed a positive benefit.

**Benefits:** Lower extremity strength training performed in individuals in the chronic stages following an acute-onset CNS injury may provide inconsistent gains in walking outcomes as compared to no exercise, conventional exercises, or alternative lower extremity training strategies.
**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 include increased hypertensive responses in individuals with cardiovascular disease, although no significant adverse events are reported beyond usual care.

**Benefit-harm assessment:** Neutral

**Value judgement:** Most strength training studies utilized exercises targeted multiple sets and repetitions of 70-100% of participants’ one repetition maximum (1RM) to target 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 70-100% 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:** Individuals with chronic CNS injury may benefit from strength training consisting of multiple sets and repetitions of >70%1RM to improve locomotor function and neuromuscular function.
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. Providing subjective Ratings of Perceived Exertion (RPE) scale around the clinic may facilitate implementation. 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\textsuperscript{54,56}. Decreased force or power is due primarily to deficits in volitional (i.e., neural) activation of the involved musculature\textsuperscript{74,75}, although peripheral changes in the muscle, including atrophy\textsuperscript{76,77}, increased stiffness\textsuperscript{78,80} and altered fiber characteristics have been observed\textsuperscript{81,82}. Deficits in power generation have been linked directly to reduced walking speed\textsuperscript{83,84}, and rehabilitation strategies designed to improve muscle strength have been suggested to improved locomotor function\textsuperscript{85-87}. 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 (i.e., sit-to-stand performance or step-ups).

Appendix Table 1 details the evidence describing the effectiveness of strength training interventions. Three Level 1 articles indicate that strength exercises utilized in individuals in the chronic stages following an acute-onset CNS injury results in limited gains in walking function as compared to alternative or no interventions. In studies by Flansbjer\textsuperscript{88} and Severinsen\textsuperscript{89},
participants with chronic stroke performed strengthening exercises of selected lower extremity muscle groups, including bilateral knee extension and flexion or bilateral knee/hip extension flexion and ankle dorsi-/plantarflexion over 10-12 weeks (20-36 sessions). Following a brief warm-up, training intensity was targeted at 80% maximum volitional contractions (MVCs), and participants performed 2-3 sets of 6-8 repetitions, with brief rest intervals (2 min) between sets. Control interventions in both groups consisted of no interventions, although in one study an additional experimental group of aerobic training was utilized (three 15-min bouts of cycle ergometry reaching 75% HR reserve over 12 weeks). Primary results of both investigations revealed no improvements in either 10-m or 6-min walk tests as compared to the comparison groups. In contrast, the study by Severinsen et al demonstrated greater improvements in 10-m walk test compared to walking results following aerobic training. Additional results include improvements in lower extremity strength in both studies as compared to control (i.e., no intervention) groups. Potential limitations of both studies included a relatively small sample size, and in Flansbjer et al the limited number of muscle groups trained (knee flexors and extensors).

In a separate study, Yang and colleagues 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 to no intervention. The functional tasks were performed in a circuit training-type protocol, although only functional strengthening exercises were practiced. Specific tasks included 30 minutes of standing exercises with attempts to reach at different distances (considered strengthening tasks by the authors), sit-to-stand training, stepping forwards, backwards or sideways onto blocks of various heights, and heel raises during standing. The number of repetitions were graded to each participant’s functional
level, and both repetitions and difficulty of tasks (e.g., height of step-ups) increased as tolerated, although specific details were not provided. Results indicated significantly greater improvements in the 10-m and 6-min walk tests in the experimental vs comparison group. In addition, strength gains of 30-40% across paretic and non-paretic legs were observed in the experimental group, with negligible improvements in the control intervention. Limitations of the present 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 to stretching or range of motion exercises on impairments or functional tasks, demonstrating inconsistent improvements in walking function. In a study by Kim and colleagues, participants post-stroke performed strengthening exercises over 6 weeks (18 sessions) targeting bilateral knee extension, dorsi- and plantarflexion forces, and whole limb extensor power generation (i.e., leg press). The comparison group performed stretching 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-/plantarflexion. 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 another study by Ouellette and colleagues, experimental exercises targeted paretic and non-paretic dorsiflexors, plantarflexors, and knee extensors, as well as bilateral leg press exercises using 3 sets of 8-10 repetitions using 70% of MVCs. Control strategies in this group 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. revealed greater walking and strength improvements in individuals with chronic stroke.
following high intensity lower vs upper extremity strength training. Lower extremity strength training was performed in a 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 40-60% MVCs and progressing to 70-90% MVCs towards the end of the 18 sessions. Limitations of these studies included the lower sample sizes, and either limited muscle groups tested or trained.

In one Level 1 and two Level 2 studies, lower extremity strengthening exercises were compared to alternative interventions. In Jayaraman et al94, participants with motor iSCI enrolled in a cross-over 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 plantarflexors, or conventional strengthening strategies, including 3 sets of 10-12 repetitions at 60-75% MVCs. The results revealed positive although non-significant improvements in 10MWT, but greater gains in the 6MWT in the higher-intensity training conditions. In another cross-over study by Labruyere and colleagues95, lower extremity strengthening exercises performed over 4 weeks (16 sessions) was compared to robotic-assisted gait training in participants with iSCI. In the strengthening interventions, 3 sets of 10 repetitions of strengthening exercises 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 vs robotic-assisted gait training. Limitations of both studies include the relatively small sample sizes and use of a cross-over design during which the lack of wash-out of previous training effects may minimize gains with the second intervention performed. Finally, Kim et al96 evaluated the effects of 40 sessions over 8 weeks of ankle
strengthening exercise plus conventional therapy as compared to balance training on the Biodex Balance System plus PT. Strength training was performed in 14 participants focusing on the dorsi- and plantarflexors 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 with 30 minutes of additional standing balance training, as compared to 40 sessions 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 10 m walk test favored the balance vs strength training group.

In a separate study, Clark and Patten analyzed the effects of different forms of strength training over 5 weeks (i.e., concentric vs eccentric) prior to 3 weeks of gait training. In participants with chronic hemiparesis post-stroke, 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 a multi-segmental tasks involved most sagittal plane muscle groups. Participants performed 3-4 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.

**Research Recommendation 1:** Specific comparisons between higher intensity (≥ 0% 1RM) strengthening interventions for multiple sets and repetitions against other task-specific
(i.e., walking interventions) should be performed to evaluate the relative efficacy of these strategies on both walking and strength outcomes.
Action Statement 2: EFFECTIVENESS OF BALANCE TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. (A) 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 with acute-onset CNS injury. (B) Clinicians should not use sitting or standing balance training with additional vibratory stimuli to improve walking speed and distance in individuals with acute-onset CNS injury. (C) Clinicians may consider use of static and dynamic (non-walking) balance strategies when coupled with virtual reality (VR) or augmented visual feedback to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong)

Action Statement Profile:

Aggregate evidence quality: Level 1. A) Based on six Level 1 and five Level 2 RCTs, exercises focused on trunk stabilization or weight shifting activities in sitting or standing, with or without altered visual or somatosensory input, demonstrate limited gains in walking function as compared to no intervention or alternative rehabilitation activities. Three articles demonstrate no differences in gait speeds following therapy activities focused on postural trunk control in sitting or standing as compared to other sitting and standing activities with limited attention towards challenging trunk stability. Four articles describing strategies to promote weight-bearing symmetry in standing or walking suggest limited benefit on walking function as compared to strategies that do not promote symmetry. Other studies provided altered visual input or surface stability during standing tasks revealed no consistent improvement in walking function as compared to other rehabilitation strategies. Of these articles, only 3 of 11 demonstrated gains in walking function in the experimental group as
compared to the control or comparison intervention. B) Based on four Level 1 RCTs examining the efficacy of postural training with whole body or local vibration, limited benefit was observed as compared to similar exercises without vibration or other interventions. Three Level 1 articles showed no benefit on locomotor outcomes of whole-body vibration coupled with postural exercises without vibration, or with a sham, low amplitude whole-body vibration training program. One Level 1 article showed a positive benefit on locomotor outcomes of local vibratory stimuli applied at the foot coupled with postural training as compared to postural training without the vibratory stimulus. Of four articles, only 1 demonstrated significantly greater improvements with the experimental (i.e., vibration) intervention. C) Based on six Level 1 and three Level 2 RCTs, clinicians may consider the use of augmented visual feedback coupled with static or dynamic (non-walking) balance to improve walking function. Two Level 1 articles and one Level 2 study showed greater differences in locomotor outcomes when comparing augmented or virtual reality coupled with static and dynamic postural exercise in additional to regular therapy, as compared to regular therapy only. Conversely, one Level 1 study revealed no improvements in walking function following augmented visual input during postural training as compared to no additional intervention. When balance training with augmented visual input is compared to an equal amount of therapy, four articles demonstrated inconsistent differences of the efficacy of augmented balance training. Finally, one Level 1 article showed no benefit of augmented dynamic balance training as compared to no therapy. In summary, 5 of 9 articles demonstrated greater improvements in walking function with VR coupled with balance training as compared to control interventions.
**Benefits:** Balance training in combination with virtual or augmented reality performed in individuals in the chronic stages following an acute-onset CNS injury may be of benefit to improve walking outcomes as compared to no intervention or as compared to 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 require 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 judgement:** There are limited details regarding the relative intensity of the postural perturbation strategies described in all studies. The findings suggest 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 prefer to utilize feedback systems during balance training to increase engagement. Alternatively, selected individuals may be hesitant to use specific technology.
**Exclusions:** There are no documented exclusions for potential participants. Studies with virtual reality often used custom-based systems, and use of commercially available systems may not result in similar outcomes.

**Quality Improvement:** Individuals with chronic CNS injury may improve walking with static balance training combined with virtual reality as available. If specific equipment is not available, therapist 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 (non-walking) tasks is a major impairment observed in individuals with acute-onset neurological injury, and is strongly associated with fall risk and reduced participation. Indeed, impaired balance is a primary predictor of locomotor function in the chronic phases following neurological injury. Training activities directed towards improving postural control in sitting and standing are a major focus of traditional rehabilitation strategies used in the clinical setting. Specific interventions have included focus on challenging postural stability of the trunk 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 (i.e., feet together or tandem), or sitting or standing on uneven surface. To augment the training experience, additional sensory inputs may
be provided, including altered visual input to provide feedback of balance performance (virtual reality), or provision of specific physical inputs such as vibratory stimuli or change the relative contributions of sensory inputs (i.e., visual vs proprioceptive) that contributed to postural stabilization.

A) Appendix Table 2a-c details the evidence describing the effectiveness of balance training interventions. Eleven studies evaluated the effects of sitting or standing balance (i.e., postural) training on walking function in individuals with acute-onset CNS injury. Three studies evaluated the effects of stabilizing the trunk during sitting or standing activities, revealing no significant improvements in walking function as compared to 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 post-stroke. In 20 individuals post-stroke, Dean and Shepherd\textsuperscript{100} examined the effects of standardized seated training program that encouraged patients to grasp objects greater than arm’s length in various directions as compared to 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 post-training between groups. In Kilinc et al\textsuperscript{101}, postural and trunk exercises performed using Bobath (i.e., neurodevelopment treatment) techniques were compared to 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 two groups. In another Level 2 study, Chun et al102 evaluated the effects of lumbar stabilization training as compared to postural standing training in individuals with chronic stroke. Over 7 weeks of training, participants with chronic stroke randomized to the experimental group received 30 min 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 degrees from vertical in multiple directions in an effort to increase trunk muscle activation. This training was compared to 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 to other exercise strategies with limited attention towards weight-bearing symmetry. In one Level 1 and three 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 non-paretic limb, and Tai Chi exercise was not improved consistently as compared to other therapeutic strategies. Aruin et al103 and Sheikh et al104 both investigated the effects of compelled weight shifting using a shoe-insert on the non-paretic limb in participants with chronic stroke. In Aruin et al103, 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. Post-training 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\textsuperscript{104} trained 28 individuals post-stroke 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 vs control group, with no changes in gait speed or any gait symmetry measures. In another study by You and colleagues\textsuperscript{105}, 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 to those observed following similar training strategies, except without the use of the device during PT activities. In 27 individuals post-stroke, there were no significant differences in the changes in locomotor function (10MWT) between the groups. In a separate study, Kim et al\textsuperscript{2015}\textsuperscript{106} compared the effects of additional 30 minutes/session of Tai Chi exercises with general PT as compared to 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, post-training assessments revealed significant differences in 10 m walk, Timed Up and Go and other measures of standing postural control in the experimental vs 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 three Level 1 and one Level 2 studies, revealing no additional gains in walking function as compared to similar exercises without altered sensory feedback. In Bonan et al\textsuperscript{107}, 20
individuals with chronic stroke were randomized to receive 20 1-hr sessions of specific balance exercises over 4 weeks, with vision occluded with a mask as compared to 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 vs control group, although there were no differences in changes in gait speed between groups. Similarly, Bayouk et al investigated the effects of balance exercises performed in 16 individuals with chronic stroke with and without altered sensory feedback. During 16 1-hr therapy sessions over 8 weeks, participants with stroke practiced dynamic balance exercises (sitting, standing, transfers, stepping in place or for limited distance walking in different 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 post-training, changes in the 10MWT were not different between groups, with additional outcomes of center of pressure sway revealing small improvements in the experimental group. Further, Kim et al evaluated the effects of 40 sessions over 8 weeks of conventional therapy with 30 minutes of additional standing balance training, as compared to 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 plantarflexors 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 vs strength training. The combined data suggest limited benefit of balance training in sitting or standing as compared to more conventional strategies. Finally, Bang et al\textsuperscript{109} evaluated the effects of an additional 30 min of standing balance activities performed on unstable (i.e., compliant foam) surfaces immediately following 30 min of treadmill training for 20 sessions over 4 weeks as compared to only 30 min sessions of treadmill training. In 12 participants post-stroke, the average changes with the additional training in the experimental vs 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 (i.e., 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.

Four Level 1 studies suggest limited improvements in locomotor performance in participants in the chronic stages following an acute-onset CNS injury 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 to other exercise activities. For example, Brogardh and colleagues\textsuperscript{110} 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 Lau et al\textsuperscript{111} \((n=82)\) and Liao et al\textsuperscript{112} \((n=84)\), WBV provided during dynamic leg exercises performed over 24-30 sessions over 2-3 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\textsuperscript{113} provided postural stability training with additional impairment-based exercises for thirty 30-min session over 6 weeks with local vibration applied over the triceps surae and tibialis anterior tendons. Changes in outcomes were compared to 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 enhance the interaction between the user and the simulated environment to increase engagement and provide feedback of performance. In six Level 1 and three Level 2 studies, the effects of augmented or virtual reality during lying, sitting, or dynamic standing (non-walking) tasks were evaluated as compared to other therapeutic activities without virtual reality or no therapy. In three Level 1 and one Level 2 studies, the effects of additional virtual or augmented reality exercise in addition to regular PT was compared with regular PT alone. In both Lee et al\textsuperscript{114} and Park et al\textsuperscript{115}, participants in the experimental group received twelve 30-minute sessions of postural VR training over 4 weeks in addition to 30 min sessions of conventional PT 5 days/week over a similar training period. The control groups received only the 30-min conventional therapy sessions. Computer-based feedback of movement was provided during supine, sitting and standing exercises in 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 one of these studies\textsuperscript{114}, with additional improvements in selective measures of balance. In addition, the study by Yom et al\textsuperscript{116} performed balance activities with augmented visual input for 30 minutes a day, 5 times a week for 4-6 weeks in addition to conventional physical therapy. In this study\textsuperscript{116}, the experimental intervention followed conventional physical therapy delivered 30 min/session, 10 sessions/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\textsuperscript{116}. In both studies, participants in the conventional rehabilitation plus balance exercises showed significantly greater improvements in walking speed compared to those who received conventional rehabilitation alone. Notably, participants in the experimental group received 150 additional min/week of motor training, which may contribute to the observed results. Also, in a study by Kim and colleagues\textsuperscript{117}, both experimental and control groups received 16 40-min 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 min session of virtual reality 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 vs control interventions.

The effects of balance training coupled with augmented or virtual reality therapy as compared to another training paradigm of equivalent duration were also assessed in two Level 1 studies and two Level 2 studies. In both Chung et al\textsuperscript{118} and Llorens et al\textsuperscript{119}, individuals with chronic stroke were randomized to either balance training combined with augmented visual feedback (virtual reality) using custom-made head-mounted virtual reality systems, or balance
training without augmented visual input. Llorens and colleagues\textsuperscript{119} provided training for 20 1-hr sessions over 4 weeks, during which participants randomized to the experimental group were provided 30 min of conventional training of standing exercises, including weight shifting, reaching tasks, 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 one foot towards a target while maintaining balance. The comparison group received 1 hr of conventional therapy. In Chung et al\textsuperscript{118}, participants were provided 18 30-min session 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 vs control training, with additional gains in selected balance measures.

In contrast, two studies by Song et al\textsuperscript{120} and Gil-Gomez et al\textsuperscript{121} found no greater improvements in locomotor function following augmented visual input during balance training as compared to training without VR or conventional strategies. Gil-Gomez et al\textsuperscript{121} reported the effects of dynamic balance training on 17 participants with acquired brain injury (i.e., stroke and TBI) using the Nintendo Wii over 20 1-hr sessions. Using three different custom-made gaming programs challenging postural stability during standing tasks, the authors found no significant improvement in the 10MWT as compared to an equivalent number of sessions focused on balance training. Similarly, Song et al\textsuperscript{120} compared the effects of VR balance training to lower extremity ergometry training in 40 participants with chronic stroke. Individuals in the experimental group performed training using the Xbox Kinect for 40 30-min 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 40 30-min 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\textsuperscript{122} 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-min 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. While improvements in both walking speed (3-m walk test) and endurance (6-min walk test) were observed in both groups, differences between groups were not significant.

The combined data suggest few significant gains following sitting and standing balance training activities alone or with additional vibratory input, although potential positive gains were observed when combined with augmented (i.e., virtual) reality systems. 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 2:** 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 3:** EFFECTIVENESS OF CYCLING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians may consider use of cycling or recumbent stepping interventions instead of alternative interventions to improve walking speed and distance in individuals in the chronic stages following an acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: weak).

**Action Statement Profile:**

**Aggregate evidence quality:** Level 2. Based on two Level 1 and three Level 2 RCTs examining whether cycling is more beneficial than conventional physical therapy or lower intensity cycling, walking, or strengthening. One Level 1 and two Level 2 articles showed a benefit of higher intensity cycling training compared to conventional physical therapy or lower intensity cycling or walking training. One Level 1 study showed no benefit for locomotor outcomes with cycling compared to high intensity resistance training or a control group. One Level 2 article showed no benefit for lower intensity cycling compared to standing exercises using virtual reality. In summary, 3 of 5 articles reviewed demonstrated significantly greater gains in walking function, as compared to other interventions.

**Benefits:** Cycling may improve locomotor outcomes in participants in the chronic stages following an acute-onset CNS injury, although a strong trend was observed for greater benefit with higher vs lower intensity cycling or other paradigms.

**Risks, harm, and costs:** Increased costs and time spent may be associated with travel to attend cycling or recumbent stepping interventions. There may also be additional costs for equipment needed to perform cycling or recumbent stepping exercises. Additional risks may
include increased potential for cardiovascular events during higher intensity training cycling without appropriate cardiovascular monitoring. The cost of equipment to monitor cardiovascular demands to ensure safe participation during evaluation and training may be warranted.

**Benefit-harm assessment:** Neutral

**Value judgement:** 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:** Despite the potential efficacy of higher intensity cycling interventions, 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:** Individuals with chronic CNS injury receiving cycling training may improve locomotor function and other aspects of cardiovascular health as compared to conventional strategies.

**Implementation and Audit:** Challenges associated with implementing cycling training may be the perceived barriers related to cardiovascular monitoring. 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 Ratings of Perceived Exertion (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**

After 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\(^1\)\(^2\),\(^3\),\(^4\).

Accordingly, seated cycling and recumbent stepping has been studied as an alternative for improving locomotor outcomes such as walking speed and endurance after acute-onset CNS injury.

The available evidence suggests that cycling or recumbent stepping training may result in better locomotor outcomes in people with chronic CNS injury as compared to other strategies, with a trend for greater improvements when performed at higher intensities. Appendix Table 3 details the evidence describing the effectiveness of cycling or recumbent stepping training interventions. One Level 1 and two Level 2 articles showed a benefit of higher intensity cycling training compared to conventional physical therapy, lower intensity cycling or walking training in individuals with chronic stroke\(^5\),\(^6\),\(^7\).

In one Level 1 and one Level 2 study, participants performed cycling exercise at 50-70% HR reserve, 40 minutes a day, 5 times per week for either 8 weeks\(^7\) or 12 weeks\(^6\). In one study\(^7\), the control group completed matched duration low intensity (20-30% HR reserve) over-ground 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, the control group completed matched duration conventional physical therapy that included 35 minutes of stretching and 5 minutes of low intensity walking at 20-30% HR reserve. In both studies, participants in the high intensity cycling group showed greater improvements in 6MWT distance compared to the control group.

In another Level 2 study, participants with chronic stroke participated in conventional physical and occupational therapy in addition to 30 minutes of high intensity (50-80% max HR) or self-selected intensity cycling 5 times 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, but there were no differences in 10MWT between groups.

One Level 1 and one Level 2 study did not find greater improvement in locomotor outcomes in persons with chronic stroke following high intensity cycling training compared to strength training. As described previously, Severinsen and colleagues trained individuals 3 times per week for 12 weeks in either 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 compared the effects of 8 weeks of lower extremity ergometry training performed over forty 30-min sessions at < 40% HR reserve to virtual reality 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.
Given the low number of studies available, this recommendation may be influenced by new studies in the next update of this CPG. Nonetheless, consideration of co-morbid conditions that would make moderate to high intensity cycling training unsafe must be undertaken. Depending on co-morbidities, a graded exercise testing with ECG assessments performed prior to implementation should be considered. 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 3:** The data regarding the efficacy of cycling exercise on walking function suggests a potential benefit if higher intensity exercise is performed, and further studies should evaluate the efficacy of cycling, particularly as compared to other, more task-specific (i.e., walking) activities.
**Action Statement 4:** EFFECTIVENESS OF CIRCUIT TRAINING ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians may consider use of circuit training or combined training strategies providing balance, strength, and aerobic exercises to improve walking speed and distance in individuals with acute-onset CNS injury as compared to alternative interventions. (Evidence quality: I-II; recommendation strength: weak)

**Aggregate evidence quality:** Level 1. Based on five Level 1 RCTs and one Level 2 trial, circuit training strategies focused on postural stability, strength training, and locomotor tasks demonstrated improved walking function as compared to interventions that do not target the lower extremities. Based on three Level 1 and one Level 2 trials, combined exercise training focused on postural stability, strength training and/or walking demonstrated improved locomotor performance as compared to interventions that do not target lower extremities or reduced intensity activities. In total, 7 of 9 studies revealed significantly greater improvements in walking function as compared to comparison conditions, although the majority of alternative strategies provided no exercise interventions or interventions that did not practice activities that target the lower extremities or trunk.

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

**Risks, harm, and costs:** Increased costs and time spent may be associated with travel to attend circuit-training interventions. There may also be additional costs for equipment needed to perform circuit-training interventions. Additional risks may include increased potential for
cardiovascular events during higher intensity circuit training without appropriate cardiovascular monitoring. The cost of equipment to monitor cardiovascular demands to ensure safe participation may be warranted.

**Benefit-harm assessment:** Neutral

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

**Intentional Vagueness:** Most comparison interventions are strategies that would not reasonably be used to improve locomotor function. Future research regarding the efficacy of this intervention against other comparison strategies may alter the recommendations at the time of CPG revision,

**Role of patient preferences:** Despite the potential efficacy of higher intensity combined interventions, 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:** Individuals with chronic CNS injury who receive appropriate intensities of combined or circuit training may improve locomotor function and other aspects of general health.

**Implementation and Audit:** Challenges associated with implementing moderate to high intensity circuit or combined training exercises may be the perceived barriers related to cardiovascular monitoring. Strategies for implementation include using devices that track HR in real-time and providing a calculator in the electronic medical systems to estimate targeted HRs, and providing RPE scales around the clinic. Providing treatment templates that require
recording of HR 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:**

Individuals with acute-onset CNS injury often present clinically with combination of impairments, such as weakness, postural instability, and decreased endurance or conditioning, that limit their ability to perform many functional tasks. Persistence of these impairments in the chronic stages post-injury continue to limit locomotor function, including both walking speeds and timed distances. Many strategies focus on individual impairments in an effort to improve functional capacity as described above, although such strategies may be limited in their effectiveness when other impairments are not addressed. Accordingly, training strategies that combine multiple interventions to target patients’ deficits have been utilized in clinical rehabilitation of patient post-CNS injury. Combined strategies include strengthening exercises, balance or postural training, and walking or cycling tasks of various durations and intensities. Similarly, circuit training combines multiple impairment-based and functional exercises, although 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 training focused on strength, balance, and locomotor deficits in the chronic stages following an acute-onset CNS injury elicits greater improvement in locomotor function as compared to no intervention, or therapy sessions that are not directed towards lower extremity impairments (please see Appendix Table 4). In six Level 1 randomized controlled trials, the effects of circuit training were evaluated in participants with
chronic stroke. In Dean et al\textsuperscript{131} and Mudge et al\textsuperscript{132}, the effects of circuit training were compared to other activities in which no leg exercises were performed. Dean and colleagues\textsuperscript{131} randomized 12 individuals into either 12 1-hr 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 post-stroke, Mudge et al\textsuperscript{132} compared the effects of 12 sessions of circuit training as compared to 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 one study\textsuperscript{131}. Cardiovascular intensities were not reported in both studies, and its effects on the outcomes observed are not clear.

Three additional studies evaluated the effects of circuit training, with focus on balance, strengthening, and/or ambulation tasks, with attention to intensity of task-practice. Both Pang et al\textsuperscript{133} and Moore et al\textsuperscript{134} recruited approximately 60 individuals post-stroke to evaluate the effects of up to 57 1-hr sessions of circuit training exercises on locomotor balance and cardiovascular function as compared to control interventions. In the experimental group, participants rotated through 3 different exercise stations of aerobic conditioning, consisting of walking and non-walking aerobic exercise, mobility and balance training, as well as functioning strengthening exercises. Participants received feedback of HR responses during training and were asked to achieve up to 40-50\% of HR reserve during the first few weeks, with intensity increased 10\%
until 70-80% HRmax. 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 Pang et al\textsuperscript{133}, whereas Moore et al\textsuperscript{134} demonstrated gains in both 10MWT and 6MWT. Additional improvements included greater gains in peak VO\textsubscript{2} in both studies in the experimental groups, whereas and the study by Moore et al\textsuperscript{134} also observed greater gains in balance with circuit training. In addition, Vahlberg and colleagues\textsuperscript{135} studied the effects of 3 months (2 times/week) of circuit training on walking function and body composition in 43 participants with chronic stroke. Participants in the experimental group received 1-hr 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 min followed by 1 min 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.

Another study by Song et al\textsuperscript{136} evaluated the effects of additional individual vs group circuit training activities plus convention therapy as compared to conventional therapy alone. Thirty participants with chronic stroke all received up to 20 30-min sessions of conventional therapy over 4 weeks, and were randomized to an additional 30 min/session of a circuit training program supervised by one therapist, additional circuit training classes supervised by two 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-min walk test were observed in both groups provided additional circuit training as compared those provided conventional therapy alone, with no differences between circuit training groups. The limitations of these findings are the lack of consistent 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 effects of combined exercise therapies without use of a circuit training paradigm has also been explicitly evaluated in two Level 1 and one Level 2 studies, with different tasks performed at variable intensities. Two Level 1 studies\textsuperscript{137-139} evaluated the effects of aerobic and strengthening or upright dynamic balance tasks at higher vs usual care or lower intensity activities. Lee et al\textsuperscript{137} evaluated the effects of 6 months of aerobic exercise using walking or cycling and various lower extremity strengthening exercises as compared to no exercises on locomotor function and arterial stiffness. Participants in the experimental group performed over 20 minutes of aerobic exercises and 30 minutes of resistance training consisting of 2-3 sets of 10-15 repetitions at 11-16 RPE. Changes in both 10MWT and 6MWT favored the experimental training, in addition to measures of transfers and postural stability. Tang et al\textsuperscript{138,139} compared 6 months of high intensity aerobic training during walking, cycling and dynamic balance activities as compared a lower intensity intervention in 50 individuals with chronic stroke. Participants in the experimental group received 1-hr sessions 3 days/week that consisted of 30-40minute 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 < 40% HR reserve to minimize aerobic challenges. Post-training assessments revealed no greater improvements in 6MWT in the experimental vs. control group, as well as no differences in peak VO₂ or measures of arterial stiffness.

In a final study, Hui-Chan and colleagues¹⁴⁰ evaluated the effects of combined physical therapy exercises as compared to a group that received no interventions. During 20 sessions provided in the home over 4 weeks, participants were randomized to receive either 60 minutes of physical therapy consisting of standing and walking exercises, no interventions, or these two interventions coupled with transcutaneous electrical nerve stimulation, that latter of which is not considered here. The results indicate very small but significant between groups differences in 10MWT and 6MWT between the exercise and no exercise group.

While the collective data demonstrate significant gains in walking function following combined or circuit training, the positive 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, and enthusiasm is therefore dampened¹³⁸,¹³⁹.

Research recommendation 4: Future studies should strongly consider evaluation of circuit and combined training interventions that carefully delineate the amounts, types and intensities of interventions compared to a matched duration therapy that could reasonably be expected to improve walking function in individuals in the chronic stages following an acute-onset CNS injury.
**Action Statement 5**: EFFECTIVENESS OF MODERATE TO HIGH INTENSITY WALKING TRAINING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should use moderate to high intensity walking training interventions to improve walking speed and distance in individuals with acute-onset CNS injury (Evidence quality: I-II; recommendation strength: strong).

**Action Statement Profile:**

**Aggregate evidence quality**: Level 1. Based on 12 Level 1 RCTs examining whether moderate to high intensity walking training, or fast walking training, result in greater benefit than other conventional physical therapy, stretching, or low intensity walking training. Eight Level 1 articles showed differences in locomotor outcomes between moderate to high intensity walking training compared to low intensity training or conventional physical therapy, such as stretching or massage. One Level 1 article showed no benefit of moderate to high intensity treadmill training compared to no intervention on locomotor outcomes. One Level 1 article showed no benefit of high intensity walking training compared to low intensity walking training on locomotor outcomes. Two Level 1 articles comparing fast to slow treadmill training showed no differences between groups on locomotor outcomes, although the fast training was not focused on achieving moderate to higher intensities. In summary, 10 articles focused directly on providing moderate to high intensity walking activities, with 8 demonstrating significant benefit over comparison groups.
**Benefits:** Moderate to high intensity walking training performed in individuals in the chronic stages following an acute-onset CNS injury is of benefit to improve walking outcomes as compared to low intensity walking training or conventional physical therapy.

**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. The cost of equipment to monitor cardiovascular demands during evaluation and training to ensure safe participation is warranted.

**Benefit-harm assessment:** Preponderance of benefit

**Value judgement:** Locomotor training appears to be effective only at moderate to high aerobic intensities (i.e., 60-80% of HR reserve). Cardiovascular conditioning appears to address the effects of deconditioning associated with stroke.

**Intentional Vagueness:** None

**Role of patient preferences:** Despite the potential efficacy of higher intensity walking training, selected individuals may prefer lower intensity activities. Conversely, others may appreciate the gains in walking function with performance of aerobic training.

**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: Individuals with chronic CNS injury will receive appropriate intensities of walking training to maximize total amount of walking practice in reduced time, resulting in improved locomotor function and other aspects of general health.

Implementation and Audit: Challenges associated with implementing moderate to high intensity circuit or combined training 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 RPE scales around the clinic. Providing treatment templates in the 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 interventions performed at moderate to high intensity (e.g., 60-80% of HR reserve) can lead to greater improvements in timed walking distance and measures of oxygen consumption as compared to lower intensity exercises in a variety of patient populations without neurological compromise, including those with significant cardiovascular compromise141,142. These findings led investigators to question whether similar findings would be observed in individuals with chronic stroke, given the high incidence of cardiovascular disease in this group143. A number of studies have investigated the effects of moderate to high intensity walking training on locomotor outcomes in those in the chronic stages following an acute-onset CNS injury.

Appendix Table 5 details the evidence describing the effectiveness of moderate to high intensity (i.e., aerobic) training interventions. Four level 1 studies examined the effects of
moderate to high intensity treadmill training in individuals with chronic hemiparesis post-stroke compared to other more passive interventions\textsuperscript{144-147}. In these 4 studies, participants in the experimental group trained on the treadmill 3x/week for 30-50 minutes per session at 60-80% HR reserve or maximum HR. Participants trained for 3\textsuperscript{144,147} or 6 months\textsuperscript{145,146}. In two of the studies\textsuperscript{145,146}, 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\textsuperscript{144} or passive exercise of the limbs with some balance activities\textsuperscript{147}. Locomotor outcomes revealed a significantly larger increase in the 6MWT in the higher intensity training groups compared to comparison interventions in all studies. Additionally, walking speed on the 10MWT was significantly greater in the experimental vs control intervention of one study\textsuperscript{144}, although walking speed was not different between groups in two studies\textsuperscript{145,146} and was not measured in another\textsuperscript{147}.

A fifth Level 1 study examined the effects of high intensity (80-85% of age predicted HR maximum) treadmill training performed 2-5x/week for 4 weeks in persons with chronic stroke who had been discharged from physical therapy due to a plateau in walking function\textsuperscript{22}. This study did not find a difference in walking speed or distance with moderate to high intensity treadmill training in those with chronic stroke.

Three of the Level I studies that compared moderate to high intensity walking training to low intensity training in those with chronic stroke also found greater improvements in locomotor outcomes in the higher intensity group\textsuperscript{148-150}. Two of these studies utilized high intensity interval training\textsuperscript{148,150}. In Boyne et al\textsuperscript{148}, participants in the high intensity group walked for 30 second bursts at their fastest possible speed, alternating with 30-60 second intervals where the treadmill was stopped. Participants in the low intensity group walked at 40-45% HR reserve. Participants trained approximately 3x/week for 12 sessions with a goal of 20-25 minutes/session. Large effect
sizes favoring the high intensity interval group were found for walking speed. In Munari et al\textsuperscript{150}, participants trained 3x/week for 50-60 minutes per week for 3 months in both groups. In the high intensity interval training, participants trained in five 1-minute intervals at 80-85\% of VO\textsubscript{2peak} separated by 3 minute intervals at 50\% VO\textsubscript{2peak}. In the low intensity group participants trained at 60\% VO\textsubscript{2peak}. 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 cross-over design\textsuperscript{149}. 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 70-80\% HR reserve (high intensity) or 30-40\% HR reserve (low intensity). Participants showed greater improvements in 6MWT following high vs low intensity training. There were no differences between groups in changes in walking speed. However, one Level I study in individuals with chronic stroke did not find significant improvements with moderate to high intensity walking training compared to low intensity training\textsuperscript{151}. In this study, participants in the high intensity group trained on a treadmill at 80-85\% of HR reserve for 30 minutes 3x/week for 6 months while participants in the low intensity group trained at <50\% HR reserve. There were no differences between groups in 10MWT or 6MWT.

One additional Level 1 study compared low to high intensity training in those with chronic iSCI\textsuperscript{152}. In this randomized cross-over design, participants trained 1 hour/day, 5 times per week for 2 months, 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. In
the low intensity training focus was on “precision training”, walking over obstacles of different
heights and onto targets of different sizes. The high intensity training resulted in significantly
higher HRs, steps per session and walking speeds during training compared to the low intensity
group. There were significant differences between groups in change in distance on the 6MWT,
but no differences in walking speed.152

An additional two studies comparing fast to slow treadmill training in persons with chronic
stroke found no differences walking speed or endurance between groups.30,153 In Awad et al153,
participants trained for 30 minutes on the treadmill and 10 minutes over ground either at their
comfortable walking speed or at their fastest possible walking speed. While no measure of
intensity was provided, it could be assumed that the participants training at the fast speed worked
at a higher intensity than those training at the slow speed. Participants trained 3x/week for 12
weeks and no differences in 6MWT or 10MWT walking speed were found between training at
the faster or slower speeds. In Sullivan et al30, participants were randomized to train at a slow
speed (0.5 mph) or fast speed (2.0 mph) for 20 minutes for 12 sessions over a 4-5 week duration.
Body-weight support up to 40% was provided and participants were allowed to rest as often as
needed. While no measure of intensity was provided, it could be assumed that the participants
training at the fast speed worked at a higher intensity than those training at the slow speed.
However, participants in the fast group were provided significantly more rest breaks than the
slow group, which could have reduced the overall training amount and intensity. While both
groups improved in their 10MWT, there was no difference between groups.

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 the disease condition(s), alternatives/modifications could include performing moderate to high intensity cycling (i.e., 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 5:** The effects of high intensity walking exercise are consistent, 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 6:** EFFECTIVENESS OF BODY WEIGHT SUPPORTED TREADMILL TRAINING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES OF AN ACUTE-ONSET CNS INJURY. Clinicians should not perform body weight supported treadmill training versus over-ground walking training or conventional training for improving walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement Profile:**

**Aggregate evidence quality:** Level 1. Based on 6 Level 1 and 3 Level 2 RCTs examining whether body weight supported treadmill training (BWSTT) is more beneficial than conventional physical therapy or over ground walking training on locomotor outcomes. Three Level 1 and two Level 2 articles showed no benefit of BWSTT compared to over ground walking training. One Level 1 article showed no benefit of BWSTT compared to conventional physical therapy on locomotor outcomes. Two Level 1 articles showed a benefit for locomotor outcomes following BWSTT compared to no intervention or following BWSTT plus conventional physical therapy compared to physical therapy only. One Level 2 article did not directly compare results of stretching plus joint mobilization and either BWSTT or over ground walking training. In summary, 2 of 9 studies detailing the effects of BWSTT over other strategies revealed greater improvements in walking function.

**Benefits:** The use of BWSTT does not improve walking outcomes compared to over ground walking training or other interventions in individuals in the chronic stages following an acute-onset CNS injury.
**Risks, harm, and costs:** Increased costs and time may be associated with travel to attend BWSTT interventions. Body weight support systems with motorized treadmills may be more expensive, and additional costs may include multiple clinicians that provide assistance during walking training.

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

**Value judgement:** 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. All participants included in these studies were also able to ambulate overground without the use of BWS. Different results may occur in individuals who are non-ambulatory or unable to ambulate without BWS.

**Intentional Vagueness:** The use of BWS and physical assistance may be contributing factors that resulted in negligible improvements with this training paradigm as compared to other strategies.

**Role of patient preferences:** Cost and patient time and transportation may play a role.

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

**Quality Improvement:** Individuals with chronic CNS injury who ambulate without physical assistance may not require substantial body-weight support or manual assistance when walking on a treadmill.
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 non-ambulatory individuals to allow stepping.

Supporting evidence and clinical implementation

Following acute-onset CNS injury, the ability to bear full body weight during walking is often impaired\textsuperscript{154-157}. 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\textsuperscript{33,157,158}. 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\textsuperscript{159-161}.

Strong evidence indicates that BWSTT compared to over ground walking training does not result in better locomotor outcomes in people in the chronic stages following an acute-onset CNS injury (please see Appendix Table 6). Three Level 1 and two Level 2 articles showed no benefit of body weight supported treadmill training compared to over ground walking training\textsuperscript{162-165} and one study showed greater benefit of over ground walking training\textsuperscript{14}. 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 3x/week for 60 minutes/session for 13 weeks with 30% body weight support at a self-selected pace with assistance to advance the leg when needed\textsuperscript{162}. This training was compared to a conventional PT
group and a group doing over ground 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 over ground group had the highest average HR during training. No differences in walking speed were found between groups162.

In a study of participants with TBI163, those in the BWSTT trained 2x/week for 14 weeks, 15 minutes/session and were compared to a group doing standard over ground 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 study34, participants with chronic stroke trained 30 minutes, 5X/week for 2 weeks in either a BWSTT or over ground walking group. In the BWSTT group, BWS began at 30% and was reduced to 15% when the participant could walk at 2.0 mph and did not require assistance from the therapist. During over ground walking, participants were encouraged to walk as fast as possible, but not to exceed the moderate intensity level. No differences between groups were found with 6MWT, however improvements in walking speed favored the over ground walking group.

In a similar study, participants with chronic stroke trained daily for 25 minutes/day, 4 days/wk for 4 weeks performing either BWSTT or over ground walking training165. 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 were increased by 0.044 m/s each day as tolerated, although intensity of training was not reported. No differences in walking speed were found between groups.

In one other study, participants with chronic stroke trained for 3 hours/day 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 over ground walking training, depending on group assignment. In the BWSTT group, BWS ranged from 8%-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 to over ground walking in persons with iSCI. Participants in both the BWSTT and control groups participated in 30 semi-weekly sessions lasting 30 minutes each consisting of passive stretching and joint mobilization and either BWSTT or over ground 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 over ground training.

In contrast to the results comparing BWSTT to over ground walking, there is some evidence that BWSTT may improve locomotor outcomes when added to conventional physical therapy or compared to no intervention in persons in the chronic stages following an acute-onset CNS
injury. Three Level 1 studies compared BWSTT 2-5x/week for 4 weeks to 1) proprioceptive neuromuscular facilitation\textsuperscript{167}, 2) no intervention\textsuperscript{168} or 3) stretching, muscle strengthening, balance, and over ground walking training\textsuperscript{169}. Of note, Yen et al\textsuperscript{169} provided BWSTT \textit{in addition} to the other exercise and participants therefore received an additional 30 minutes 3x/week of BWSTT. Participants in the BWSTT group trained at a variety of speeds, including as fast as possible\textsuperscript{168}, their comfortable speed\textsuperscript{167} or according to subject ability\textsuperscript{169}. Participants were provided 20-40\% 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 $>15$ degree knee flexion during stance\textsuperscript{167,169}. In two of the studies, participants were assisted by 1-2 therapists to help achieve normal kinematics\textsuperscript{167,169}. In the third study, there was no indication that assistance was provided by therapists during walking\textsuperscript{168}. 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\textsuperscript{168,169} and one study found no differences between groups\textsuperscript{167}. Importantly, participants in the study by Yen et al\textsuperscript{169} received BWSTT \textit{in addition} to other therapy, while outcomes from the Takao et al\textsuperscript{168} study compared BWSTT to no intervention. These differences in protocols may account for the differences in outcomes.

All participants included in these studies were already able to ambulate without the use of BWS. This recommendation may therefore not apply to non-ambulatory individuals or those who require BWS to ambulate due to impairments from the CNS injury or to other co-morbid conditions.

\textbf{Research recommendation 6:} Further studies should evaluate the amounts and intensities (cardiovascular demands) of stepping activities during BWSTT to ensure patient effort and volitional engagement.
**Action Statement 7:** EFFECTIVENESS OF ROBOTIC-ASSISTED WALKING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should not perform walking interventions with robotics to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement Profile:**

**Aggregate evidence quality:** Level 1. Based on 10 Level 1 and 5 Level 2 randomized clinical trials examining whether walking training with robotics is more beneficial than walking training alone, conventional physical therapy, seated robotics or strengthening. Six Level 1 and one Level 2 article showed no greater benefit of walking training with robotics compared to walking training alone on locomotor outcomes in people with chronic CNS injury. Two Level 1 and two Level 2 articles showed no benefit for locomotor outcomes with walking training with robotics compared to conventional physical therapy, strengthening or seated robotics. Two Level 1 and two Level 2 articles showed no differences between providing robotic swing resistance or assistance during walking training on locomotor outcomes in people with chronic CNS injury. In summary, 11 studies compared robotic-assisted walking training to alternative strategies, with only 2 studies demonstrating greater gains in walking function favoring the experimental treatment.

**Benefits:** Walking interventions with robotics do not improve locomotor outcomes compared to walking interventions without robotics or conventional therapy in persons with chronic CNS injury.
**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 more expensive, and additional costs may include BWS systems used in conjunction with robotic assistance. Skin irritation and leg pain have occurred with robotic training.

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

**Value judgement:** 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. Different results may occur in individuals who are non-ambulatory 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 to other strategies.

**Role of patient preferences:** While selected individuals may wish to engage with advanced technology, others may be fearful of participation.

**Exclusions:** Given the use of primary outcomes of walking speed or timed distance, most studies likely included only participants who were able to ambulate without robotic assistance. This recommendation may not apply to non-ambulatory individuals or those who require robotic assistance to ambulate.
Quality improvement: Minimizing use of robotic-assisted device during walking training in ambulatory individuals with CNS injury may increase volitional neuromuscular activity and cardiovascular demands as compared to walking with assistance.

Implementation and Audit: Clinics may add specific “check-box” or documentation requirements for the use of robotics that could then be readily identified in a chart audit to determine adherence to the guideline.

Support evidence and clinical implementation

After chronic CNS injury, abnormal walking patterns are common. Robotic devices have been developed to assist with labor-intensive walking training that focuses on producing more normal walking patterns after chronic CNS injury. Strong evidence (5 Level 1 and 1 Level 2 article) indicates that walking training with robotics compared to walking training alone does not result in better locomotor outcomes in people in the chronic stages following an acute-onset CNS injury (please see Appendix Table 7). In 4 of the studies, participants participated in walking training with the Lokomat robot and body weight support of 10-35%, and the control group trained with BWS (10-30%) and manual assistance from a therapist during treadmill walking. In Field-Fote and Roach, participants were also assigned to an over ground walking group or a treadmill training group with electrical stimulation. Training ranged from 12 or 18 sessions, up to 60 sessions, with each session between 20-45 minutes in duration. Training speeds also varied between studies. In Esquenazi et al, speed was set to the self-selected walking velocity, which was reassessed at every 3rd training visit. In Hornby et al, 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.
Westlake et al, 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 Field-Fote and Roach were encouraged to walk as fast as possible. Significant differences in walking speed between groups were found only in Hornby et al and favored the non-robotics group. Differences in walking distance between groups were found only in Field-Foote and Roach and were also in favor of the non-robotic 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. In these studies, participants in the robotics group trained with an electromechanical gait trainer with body weight support or a Stride Management Assistance device that provides assistance at each hip joint during over ground walking. In Peurala et al, participants were assigned to a robotic walking training group, a robotic training and lower extremity electrical stimulation group, or an over ground 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 Buesing et al, participants in the non-robotic group completed high intensity treadmill training (75% HRmax) and functional mobility training. In the robotics group, participants trained at high intensity over ground (75% HRmax) along with functional walking training including multiple surfaces, obstacles and stairs. Participants in both groups trained for 45 min/session, 3 times per week for 6-8 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, participants were assigned to a Lokomat treadmill training group with up to 40% body weight...
support 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 1-2 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 (two Level 1 and two Level 2 studies) that walking training with robotics does not result in better locomotor outcomes for people with chronic CNS injury compared to conventional physical therapy, seated robotic training or strengthening\textsuperscript{95,181-183}. In Stein et al\textsuperscript{181}, participants wore a powered knee orthosis and participated in walking and functional mobility training for approximately 50 min 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\textsuperscript{181}.

In Forrester et al\textsuperscript{182}, participants were assigned to walking training with an ankle robot or to an ankle exercise group with the ankle robot. Both groups trained 3 times per week for 6 weeks. Walking training occurred at participants preferred speed and level of robotic assistance was decreased as tolerated. There were no differences in walking speed between groups following training. In Labruyère et al\textsuperscript{95}, participants with SCI either trained on the Lokomat or completed lower extremity strength training for 45 minutes, 4x/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 1-2 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, 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-min 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 post-training was not compared across groups, but there was a significant difference in gait speed between the two groups at the post-training 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. Two studies examined persons with chronic spinal cord injury and one in individuals post-stroke, training 3 times per week, 12-36 sessions with either external swing assistance or resistance provided by either a cable driven robotic device or the Lokomat. 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 cross-over design, 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.
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 not apply to non-ambulatory individuals or those who require robotic assistance to ambulate due to significant impairments or to other co-morbid conditions. Further, most studies did not indicate targeted or achieved training intensities, which have been postulated to account for some of the inconsistent and negative findings188.

**Research recommendation 7:** Further studies should evaluate the amounts and intensities of stepping activities during experimental robotic therapies to ensure patient effort and volitional engagement.
**Action Statement 8:** EFFECTIVENESS OF VIRTUAL REALITY WALKING INTERVENTIONS ON LOCOMOTOR FUNCTION IN PERSONS IN THE CHRONIC STAGES FOLLOWING AN ACUTE-ONSET CNS INJURY. Clinicians should use virtual reality training interventions coupled with walking practice to improve walking speed and distance in individuals with acute-onset CNS injury. (Evidence quality: I-II; recommendation strength: strong).

**Action Statement Profile:**

**Aggregate evidence quality:** Level 1. Based on five Level 1 and three Level 2 RCTs examining whether virtual reality (VR) training coupled with walking practice is more beneficial than other therapy interventions, including conventional physical therapy, stretching, or walking training alone. Four Level 1 articles and one Level 2 article showed differences in locomotor outcomes between VR training coupled with walking practice and any comparison group. One Level 1 article showed no benefit of VR training with cognitive load coupled with walking practice and VR training without cognitive load coupled with walking practice on locomotor outcomes. One Level 2 article showed no benefit of VR training coupled with walking practice compared to community ambulation training. One Level 2 article showed benefit of VR training coupled with walking practice compared to over ground walking practice with obstacles on locomotor outcomes. In summary, 6 of 8 studies evaluating the efficacy of walking training coupled with VR indicate significantly greater gains in walking function as compared to alternative interventions.
**Benefits:** Virtual reality training in combination with walking training performed in individuals following chronic CNS injury improves walking outcomes as compared to walking training alone, stretching, or conventional physical therapy.

**Risks, harm, and costs:** Training in a virtual environment may cause dizziness and the necessary equipment may not be readily available to clinicians and/or may be expensive.

**Benefit-harm assessment:** Preponderance of benefit.

**Value judgement:** Training in a virtual environment allows safe practice of challenging (virtual) 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 virtual reality systems. This recommendation may not directly apply to use of commercially available VR systems.

**Quality Improvement:** Individuals with chronic CNS injury can receive walking training using virtual reality 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 while increasing volitional engagement and attention.
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 (please see balance training with virtual reality).

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.38,189-191. 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 allow individuals with gait dysfunction following CNS injury to be engaged within an illusion of three-dimensional space, allowing interaction between the user and the simulated but challenging visual context through the computer interface in a safe environment.192. Interactions with a virtual environment may increase participation and motivation to perform walking practice.193,194.

Strong evidence indicates that VR coupled with walking practice utilized in individuals in the chronic stages following an acute-onset CNS injury results in gains in walking function as compared to alternative interventions (please see Appendix Table 8). Five level 1 studies examined the effects of VR coupled with walking practice in individuals with chronic hemiparesis post-stroke. In 4 of these studies and one additional level 2 study in addition to conventional rehabilitation, participants participated in VR coupled with treadmill training compared to treadmill training alone, with both groups receiving additional conventional therapy. In 2 studies, conventional rehabilitation also included lower extremity functional electrical stimulation. One study also had a control group that completed stretching exercises.
in addition to conventional rehabilitation. In 3 of the studies, 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 one study, 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. Participants in all studies walked on the treadmill with or without VR for 20-30 minute sessions, 3x/week for 3-6 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 to treadmill training alone (or control group in Kang et al) in all 5 studies. Additionally, distance on the 6MWT was significantly greater in the VR-coupled treadmill training groups compared to treadmill training alone or control groups, although 6MWT was not used in the other studies.

One additional Level 1 study did not find a difference in locomotor outcomes when VR was coupled with treadmill training compared to 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, 5x/week for 4 weeks. Both VR groups showed a significant improvement in gait speed pre to post-training, 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 post-stroke. The study by Kim and colleagues randomized
participants to one of three groups. The control group consisted of usual physical therapy for ten, 30-minute sessions/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 min sessions, three times/week for four 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/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 sec. Walking speed and distance on the 6MWT were not different between the VR-coupled treadmill training group and either of the other two groups. In the other Level 2 study, participants were randomized to walking on a treadmill and stepping over virtual objects or walking over ground and stepping over obstacles. Participants walked at their self-selected speed and in one 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 post-training.

Differences between methods for providing VR environments may contribute to variations in outcomes between studies. While 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 8:** Future studies should evaluate measures of training intensity to evaluate its 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.
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 (i.e., n=4) for inclusion in this CPG. Studies detailing the efficacy of non-walking interventions included evaluation of the effects of action observation/mental practice\(^{204-206}\), vibration on the lower leg in supine positions\(^{207}\), active and passive range of motion of impaired ankle\(^{208}\), device-assisted, seated, bilateral leg movements\(^{209}\) or ankle exercises coupled with visual feedback\(^{210,211}\) or ankle exercise with mirror feedback\(^{212}\).

Additional studies that focused on walking training included three studies that used rhythmic auditory stimulation during walking\(^{213-215}\), two that used community-based ambulation training\(^{39,216}\), one that incorporated daily stepping feedback with treadmill walking\(^{217}\), and inclined\(^{218}\), turning\(^{219}\), obstacle-crossing\(^{220}\) treadmill exercises. Other studies utilized assisted arm-swing with treadmill walking\(^{221}\), incorporated dual task performance\(^{222}\), compared treadmill training without BWS to overground training\(^{214,223}\), and two studies evaluated treadmill training with postural corrections\(^{224}\) or provided with feedback of spatiotemporal gait patterns\(^{225}\). Many of these studies demonstrated positive findings compared to the control interventions, and future revisions of this CPG may incorporate these findings given sufficient, corroborative evidence.
Summary and Clinical Implementation

The present CPG summarizes the relative efficacy of interventions to improve locomotor speed and timed distance in individuals at least 6 months following stroke, iSCI, or TBI, with attention towards the training parameters that can influence motor recovery. Recommended interventions (Table 6) that should be performed include gait training at higher intensities or combined with augmented visual feedback (i.e., virtual reality). Strategies with inconsistent evidence of efficacy include strength training, lower extremity cycling, circuit training, and standing balance exercises when combined with augmented (virtual reality) feedback. Strategies that are not recommended included sitting and standing balance training or weight-shifting exercises without augmented visual input (VR), 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 suggest all three play a role in the efficacy of rehabilitation strategies, although no single training parameter was sufficient to elicit positive outcomes.

For example, the amount of task-specific practice was considered an important variable, and the recommended interventions, including high-intensity locomotor training and VR-enhanced walking, both provide extended durations of stepping practice. However, interventions that
provided large amounts of stepping activity, such as BWSTT and robotic-assisted walking training, were not recommended. A key difference between these strategies may be the intensity of practice or volitional engagement during exercises. Greater neuromuscular activity is certainly required during higher intensity locomotor interventions to achieve the desired HR ranges. Further, VR-guided activities\textsuperscript{192} may provide greater volitional engagement with visual feedback or incorporation of salient or goal-directed tasks\textsuperscript{193,194}, which in turn may increase neuromuscular and cardiac demands. Conversely, cardiac demands during treadmill training with BWS and manual assistance or robotic-assisted training may be limited\textsuperscript{188,226}, particularly if these techniques provide substantial amounts of physical guidance\textsuperscript{227,228}. 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 intensity may be a key training parameter underlying the outcomes achieved.

While specific walking training paradigms were recommended, other interventions that did not involve substantial amounts of stepping practice demonstrated inconsistent findings. For example, circuit or combined exercise training, cycling training or strength training provided at relatively high intensities were provided weak recommendations, as these studies evaluating these interventions did not demonstrate consistent walking improvements. Balance training with additional visual feedback also demonstrated inconsistent benefits across studies, whereas seated and standing balance training without feedback resulted in negligible improvements above alternative strategies. The cumulative data suggest strategies that provide large amounts of task-specific (i.e., walking practice, particularly at higher cardiovascular intensities or with salient visual feedback, can improve walking speed and timed distance, while non-specific and reduced intensity interventions result in inconsistent or negligible gains in locomotor function.
Clinical implications

These recommendations were developed in an effort to educate clinicians and facilitate clinical adoption of evidence-based strategies as described in this guideline. An important consideration regarding potential 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 post-injury (>6 months), and primary outcomes were walking speed or timed distance. While these criteria were utilized to minimize the variation of natural recovery or use of subjective outcomes, many individuals receive rehabilitation services early following injury, during which the extent of disability is typically more substantial. A potential concern is that this guideline may not directly translate to individuals early post-injury who are non-ambulatory, which may hamper implementation in the clinical setting.

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. 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 specifics of single training strategies.

More directly, available literature suggests the current recommendations may extrapolate to individuals with subacute injury, consistent with the training parameters that appear to influence locomotor training (i.e., 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 to lower intensity walking or more conventional
interventions²³⁰. Conversely, providing stepping training without attempts to achieve higher intensity in subacute stroke can result in less optimal outcomes, as observed with robotic-assisted locomotor training²³¹ and BWSTT with manual assistance²³²,²³³. When evaluating non-specific (i.e., non-walking) interventions, the use of strength training²³⁴ or balance training²³³,²³⁴, even with additional biofeedback, has also been shown to lead to inconsistent improvements as compared to conventional strategies.

In evaluating data in non-ambulatory patient populations, greater attention to these key training parameters is warranted. For example, studies comparing the efficacy of BWSTT to treadmill stepping without BWS³³ or to overground walking²³⁵,²³⁶ demonstrate significantly greater gains in locomotor independence and function in those who were non-ambulatory or walked <0.2 m/s²³⁷. While 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 assistance²³⁷. While these strategies may be helpful following subacute CNS injury, clinicians should still utilize the potentially important training variables (e.g., intensity, saliency, and amount of practice) that may influence walking outcomes. More directly, provision of large amounts of stepping practice may be warranted, and could be enhanced with greater cardiovascular and neuromuscular intensity, or with provision of augmented feedback. Monitoring HR during these or any training sessions may be extremely valuable to ensure appropriate intensities and increased volitional engagement are achieved. Discussion of all pertinent research in non-ambulatory participants with subacute injury is beyond the scope of this CPG. Nonetheless, it is imperative that development of additional
guidelines bridge the current gaps in knowledge related to the efficacy of interventions in subacute populations.

**Implementation recommendations**

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 include 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 clinical practice guidelines (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 (see Methods) helped to identify commonly utilized treatment strategies to improve walking outcomes in the patient populations addressed. Preferred practice patterns revealed in line with the recommendations are considered facilitators, including over ground 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 (i.e., cardiovascular) responses to exercise may be of
value, although their cost and availability in clinics may be perceived barriers that are likely not
difficult to overcome. Other more costly equipment, including safety harness systems over a
 treadmill or overground to enhance the safety of higher intensity activities, may present as
greater barriers, although new equipment funds could be directed towards those systems rather
than other technology or equipment that appears to be less effective.

Additional barriers include commonly used practice patterns that may be less effective than
those described here, 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 are embedded into many neurological
rehabilitation textbooks and doctoral and residency-level educational curricula as a standard
method to address potential gait deficits. 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. As such, the efficacy of these strategies are not certain and implementation
strategies could be directed towards attempts to limit these practice patterns, or de-implement
these strategies 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 does not require expensive equipment and
can be readily performed with or without specialized equipment, although specific harness
systems can be beneficial as addressed above. As such, these interventions can be implemented
in most locations and without significant resources related to patient travel to reach specialty
clinics. Other strategies that may be considered for use to improve walking include high intensity strengthening and cycling exercise, which also require limited additional resources beyond those found at standard rehabilitation clinics. Alternatively, the cost of walking training with augmented feedback or VR may not be prohibitive, but likely requires some additional funds for commercially available systems to utilize during stepping interventions. However, an important consideration is that many of the studies reviewed utilized VR systems that are not commercially available and the use of other devices during walking training may not provide the same efficacy as the systems detailed in the articles.

Recommendations. The following are strategies that may useful for clinicians when implementing the Action Statements in this CPG. More detailed information will be provided by the implementation team assembled by the Academy of Neurologic Physical Therapy.

- 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 (e.g., HR monitors, sphygmomanometers) to ensure safety during higher intensity interventions, or visual-feedback (virtual reality) systems to increase patient engagement.
- Implement automatic prompts in electronic medical records that will facilitate obtaining orders to attempt higher intensity training strategies, 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 (e.g., 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 below, although additional recommendations deserve specific attention. To begin, there is a stark difference in the number of studies focused on individuals with TBI, as compared to those with SCI, and particularly as compared to individuals with stroke. While the number of individuals with chronic SCI are much lower than those post-stroke, the number of individuals with TBI is substantial, despite the limited number of studies that specifically target this patient population. Greater effort should be directed towards evaluating the efficacy of different strategies for improving locomotor function in these underrepresented populations.

In addition, while the inclusion of only RCTs (i.e., Level 1 or 2 studies) is considered a strength of these guidelines, there are nonetheless limitations of selected literature utilized. In particular, many of the studies recruited very small sample sizes, and hence may have been underpowered to show a statistical difference in measures of walking speed or distance. While
there are a substantial number of non-randomized and randomized studies to evaluate the effects of physical interventions on walking function, a strong recommendation is for future trials is to ensure adequate number of patients and performance of power analysis prior to initiation of enrollment.

Conclusions

The available evidence related to strategies to improve locomotor recovery following 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: Specific comparisons between higher intensity (≥ 70% 1RM) strengthening interventions for multiple sets and repetitions against other task-specific (i.e., walking interventions) should be performed to evaluate the relative efficacy of these strategies on both walking and strength outcomes.

Research Recommendation 2: 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 3: The data regarding the efficacy of cycling exercise on walking function suggests a potential benefit if higher intensity exercise is performed, and further studies should evaluate the efficacy of cycling, particularly as compared to other, more task-specific (i.e., walking) activities.

Research recommendation 4: Future studies should strongly consider evaluation of circuit and combined training interventions that carefully delineate the amounts, types and intensities of interventions compared to a matched duration therapy that could reasonably be expected to improve walking function.

Research recommendation 5: The results 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 towards >90% of HR_{max}, as performed during interval training, should be assessed.
Research recommendation 6: Further studies should evaluate the amounts and intensities (cardiovascular demands) of stepping activities during BWSTT to ensure patient effort and volitional engagement.

Research recommendation 7: Further studies should evaluate the amounts and intensities of stepping activities during experimental robotic therapies to ensure patient effort and volitional engagement.

Research recommendation 8: Future studies should evaluate measures of training intensity to evaluate its 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.
42. States RA, Pappas E, Salem Y. Overground physical therapy gait training for chronic stroke patients with mobility deficits. The Cochrane database of systematic reviews 2009:CD006075.
46. https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/SNFPPS/therapyresearch.html. (Accessed Aug. 20, 2018,
97. Clark DJ, Patten C. Eccentric versus concentric resistance training to enhance neuromuscular activation and walking speed following stroke. Neurorehabilitation and neural repair 2013;27:335-44.
120. Song GB, Park EC. Effect of virtual reality games on stroke patients' balance, gait, depression, and interpersonal relationships. Journal of physical therapy science 2015;27:2057-60.


194. Lewis GN, Rosie JA. Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users? Disability and rehabilitation 2012;34:1880-6.


### Tables and Figures

*Table 1. Example of PICO Search Terms for strength training*

<table>
<thead>
<tr>
<th>Patient populations</th>
<th>stroke</th>
<th>spinal cord injury</th>
<th>brain injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention</td>
<td>Strength training</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcomes</td>
<td>Walking</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“gait”[mh] OR “gait”[tw] OR “walking”[mh] OR walk*[tw]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

mh=Medical subject heading; tw=the word or phrase anywhere in the title/abstract;  
*=truncation symbol; picks up plurals, gerunds, etc.
Table 2. Survey results.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-ground walking</td>
<td>91%</td>
</tr>
<tr>
<td>Aerobic training</td>
<td>13%</td>
</tr>
<tr>
<td>Balance</td>
<td>64%</td>
</tr>
<tr>
<td>Robotic-assisted walking</td>
<td>8%</td>
</tr>
<tr>
<td>Treadmill</td>
<td>40%</td>
</tr>
<tr>
<td>Circuit training</td>
<td>4%</td>
</tr>
<tr>
<td>Strengthening</td>
<td>27%</td>
</tr>
<tr>
<td>Tai Chi</td>
<td>1%</td>
</tr>
<tr>
<td>Neurofacilitation</td>
<td>26%</td>
</tr>
<tr>
<td>Aquatic</td>
<td>0%</td>
</tr>
<tr>
<td>Functional electrical stimulation</td>
<td>18%</td>
</tr>
<tr>
<td>Vibration platform</td>
<td>0%</td>
</tr>
</tbody>
</table>
Table 3. Grading Levels of Evidence.

<table>
<thead>
<tr>
<th>Level</th>
<th>Standard Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>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 ≥ 50% of criteria).</td>
</tr>
<tr>
<td>II</td>
<td>Evidence obtained from lesser-quality diagnostic studies, prognostic or prospective studies, cohort studies or randomized controlled trials, meta analyses or systematic reviews (e.g., weaker diagnostic criteria and reference standards, improper randomization, no blinding, &lt;80% follow-up) (critical appraisal score &lt;50% of criteria).</td>
</tr>
<tr>
<td>III</td>
<td>Case-controlled studies or retrospective studies</td>
</tr>
<tr>
<td>IV</td>
<td>Case studies and case series</td>
</tr>
<tr>
<td>V</td>
<td>Expert Opinion</td>
</tr>
<tr>
<td>Grade</td>
<td>Level of Obligation</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>A</td>
<td>Strong</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Weak</td>
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<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Theoretical / foundational</td>
</tr>
<tr>
<td>P</td>
<td>Best practice</td>
</tr>
<tr>
<td>R</td>
<td>Research</td>
</tr>
<tr>
<td>Grade</td>
<td>Level of Obligation</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>A (strong) or B (moderate)</td>
<td>Intervention <strong>should be performed</strong></td>
</tr>
<tr>
<td>C (weak)</td>
<td>Intervention <strong>may be considered</strong></td>
</tr>
<tr>
<td>A (strong) or B (moderate)</td>
<td>Intervention <strong>should not be performed</strong></td>
</tr>
</tbody>
</table>
### Table 6. Final recommendations for CPG on Locomotor Function

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Intervention strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interventions <strong>should be performed</strong></td>
<td>• Aerobic (moderate to high) intensity walking training (intensities &gt; 60% HR reserve or 70% HR&lt;sub&gt;max&lt;/sub&gt;)&lt;br&gt;• VR-coupled treadmill training</td>
</tr>
<tr>
<td>Interventions <strong>may be considered</strong></td>
<td>• Strength training of multiple sets and repetitions at &gt;70% IRM&lt;br&gt;• Circuit training (intensities &gt; 60% HR reserve or 70% HR&lt;sub&gt;max&lt;/sub&gt;)&lt;br&gt;• Cycling training (particularly at higher intensities)&lt;br&gt;• VR-coupled standing balance training</td>
</tr>
<tr>
<td>Interventions <strong>should not be performed</strong></td>
<td>• Sitting and standing balance without augmented visual input&lt;br&gt;• Robotic-assisted walking training&lt;br&gt;• BWSTT with physical therapist assistance</td>
</tr>
</tbody>
</table>
Figure. Flow chart for article searches and appraisals
**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; strength of the article, including the level of evidence (1 or 2) and the scored section (Section B) from the CAT-EI; population diagnosis; indication of significant differences observed between treatment groups for either the 6MWT or the 10MWT (detailed below); 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.
### Appendix Table 1: strength training

<table>
<thead>
<tr>
<th>Article</th>
<th>Level (score)</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengthening vs no exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flansbjer 2008(^{88})</td>
<td>1 (13)</td>
<td>CVA</td>
<td>24</td>
<td>O</td>
<td>O</td>
<td>2X 6 to max reps 80% 1RM, 2X/wk, 10 wks</td>
<td>No intervention</td>
</tr>
<tr>
<td>Severinsen 2014(^{49})</td>
<td>1 (14)</td>
<td>CVA</td>
<td>43</td>
<td>O</td>
<td>O</td>
<td>3x8 reps 80% 1RM, 3X/wk, 12 wks</td>
<td>2 groups – aerobic, 3X/wk, 12 wks and none</td>
</tr>
<tr>
<td>Yang 2006(^{60})</td>
<td>1 (14)</td>
<td>CVA</td>
<td>48</td>
<td>+</td>
<td>+</td>
<td>functional strength exercises, 3X/wk, 1 mo</td>
<td>No intervention</td>
</tr>
<tr>
<td><strong>Strengthening vs min exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bourbonnais 2002(^{51})</td>
<td>1 (10)</td>
<td>CVA</td>
<td>26</td>
<td>+</td>
<td>+</td>
<td>up to 70-90%, reps incr, 3X/wk, 6 wks</td>
<td>Upper extremity exercise, 3X/wk, 6 wks</td>
</tr>
<tr>
<td>Kim 2001(^{91})</td>
<td>1 (13)</td>
<td>CVA</td>
<td>20</td>
<td>--</td>
<td>O</td>
<td>3x10 reps max effort, 3X/wk, 6 wks</td>
<td>passive LE ROM, 3X/wk, 6 wks</td>
</tr>
<tr>
<td>Ouellette 2004(^{55})</td>
<td>1 (12)</td>
<td>CVA</td>
<td>42</td>
<td>O</td>
<td>O</td>
<td>3x10 reps 70% 1RM, 3X/wk, 12 wks</td>
<td>LE ROM, UE exercise, 3X/wk, 12 wk</td>
</tr>
<tr>
<td><strong>Strength vs other LE exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jayaraman 2013(^{34})</td>
<td>2 (9)</td>
<td>SCI</td>
<td>5</td>
<td>+</td>
<td>--</td>
<td>3x10 reps 100% 1RM, 3X/wk, 1 mo</td>
<td>3x12 reps, 60% 1RM, 3X/wk, 1 mo</td>
</tr>
<tr>
<td>Kim 2016(^{96})</td>
<td>2 (9)</td>
<td>CVA</td>
<td>27</td>
<td>O</td>
<td>O*</td>
<td>strength 70% 1RM reps not listed, 5X/wk 2 mo</td>
<td>balance training, 5X/wk 2 mo</td>
</tr>
<tr>
<td>Labruyere 2014(^{59})</td>
<td>1 (10)</td>
<td>SCI</td>
<td>9</td>
<td>--</td>
<td>+</td>
<td>3x10-12 reps 70% 1RM, 4X/wk, 1 mo</td>
<td>Lokomat, 4X/wk, 1 mo</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clark 2013(^{97})</td>
<td>1 (14)</td>
<td>CVA</td>
<td>34</td>
<td>--</td>
<td>O</td>
<td>Eccentric strength training</td>
<td>Concentric strength training</td>
</tr>
</tbody>
</table>
Appendix Table 2A: Balance: sitting/standing with altered feedback/weight-shift:

<table>
<thead>
<tr>
<th>Article</th>
<th>Level (score)</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trunk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dean 1997100</td>
<td>1 (12)</td>
<td>CVA</td>
<td>20</td>
<td>--</td>
<td>O</td>
<td>sitting/reaching &gt; arm’s length, 5X/wk, 2 wks</td>
<td>sitting/reaching &lt; arm’s length, 5X/wk, 2 wks</td>
</tr>
<tr>
<td>Kilinc 2016101</td>
<td>1 (12)</td>
<td>CVA</td>
<td>22</td>
<td>--</td>
<td>O</td>
<td>NDT/trunk exercises, 3X/wk, 3 mo.</td>
<td>PT, 3X/wk, 3 mo.</td>
</tr>
<tr>
<td>Chun 2016102</td>
<td>2 (8)</td>
<td>CVA</td>
<td>28</td>
<td>--</td>
<td>O*</td>
<td>Lumbar stab. In standing, 3/wk, 7 wks</td>
<td>Standing training (Biodex), 3/wk, 7 wks</td>
</tr>
<tr>
<td><strong>Standing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>trunk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kline 2016101</td>
<td>1 (12)</td>
<td>CVA</td>
<td>22</td>
<td>--</td>
<td>O</td>
<td>Tai Chi 2X/wk, + regular PT, 10X/wk, 6 wks</td>
<td>regular PT, 10X/wk, 6 wks</td>
</tr>
<tr>
<td>Chun 2016102</td>
<td>2 (8)</td>
<td>CVA</td>
<td>28</td>
<td>--</td>
<td>O</td>
<td>Compelled weight shift during PT, 6X/wk, 6 wks</td>
<td>PT activities, 1X/wk, 6 wks</td>
</tr>
<tr>
<td>You 2016105</td>
<td>2 (7)</td>
<td>CVA</td>
<td>27</td>
<td>--</td>
<td>O</td>
<td>Standing with device, limited parameters</td>
<td>Single limb activities, limited parameters</td>
</tr>
<tr>
<td><strong>Standing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>weight shift</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bang 2014109</td>
<td>1 (10)</td>
<td>CVA</td>
<td>12</td>
<td>--</td>
<td>O</td>
<td>balance w/ unstable surface 30 min + 30 min TM, 5X/wk, 1 mo.</td>
<td>30 min TM, 5X/wk, 1 mo.</td>
</tr>
<tr>
<td>Bayouk 2006108</td>
<td>1 (11)</td>
<td>CVA</td>
<td>16</td>
<td>--</td>
<td>O</td>
<td>Dynamic sit/standing with EC/foam, 2X/wk, 8 wks</td>
<td>Dynamic sit/standing, 2X/wk, 8 wks</td>
</tr>
<tr>
<td>Bonan 2004107</td>
<td>1 (10)</td>
<td>CVA</td>
<td>20</td>
<td>--</td>
<td>O</td>
<td>balance w/o vision + PT, 5X/wk, 1 mo.</td>
<td>balance with vision + PT, 5X/wk, 1 mo.</td>
</tr>
<tr>
<td>Kim 2016106</td>
<td>2 (8)</td>
<td>CVA</td>
<td>27</td>
<td>--</td>
<td>O</td>
<td>Biodex Balance System + PT, 5X/wk 2 mo.</td>
<td>Strength training + PT, 5X/wk 2 mo.</td>
</tr>
</tbody>
</table>

*authors indicate difference without direct comparisons of treatment groups
### Appendix Table 2B: Balance – augmented feedback with vibration

<table>
<thead>
<tr>
<th>Article</th>
<th>Level (score)</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brogardh</td>
<td>1 (17)</td>
<td>CVA</td>
<td>31</td>
<td>O</td>
<td>-</td>
<td>Platform 3.75 mm anap, freq: 25 Hz, standing, 2X/wk, 6 wks</td>
<td>Platform 0.2 mm, freq: 25 Hz, standing, 2X/wk, 6 wks</td>
</tr>
<tr>
<td>Lau 2012</td>
<td>1 (18)</td>
<td>CVA</td>
<td>82</td>
<td>O</td>
<td>O</td>
<td>Platform +dynamic LE exercise, 3X/wk, 8 wks</td>
<td>Dynamic LE exercise, 3X/wk, 8 wks</td>
</tr>
<tr>
<td>Lee 2013</td>
<td>1 (13)</td>
<td>CVA</td>
<td>31</td>
<td>-</td>
<td>+</td>
<td>segmental vibration: 30'; dynamic standing balance + PT/FES, 5X/wk, 6 wks</td>
<td>dynamic standing balance + PT/FES, 5X/wk, 6 wks</td>
</tr>
<tr>
<td>Liao 2016</td>
<td>1 (18)</td>
<td>CVA</td>
<td>84</td>
<td>O</td>
<td>O</td>
<td>Platform + dynamic LE exercise, 3X/wk, 8 wks</td>
<td>Dynamic LE exercise, 3X/wk, 8 wks</td>
</tr>
</tbody>
</table>
## Appendix Table 2C: Balance: Augmented visual feedback

<table>
<thead>
<tr>
<th>Level of Balance</th>
<th>Article</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR-balance + PT</td>
<td>Kim 2009&lt;sup&gt;17&lt;/sup&gt;</td>
<td>24</td>
<td>--</td>
<td>+</td>
<td>VR dynamic balance 4Xwk/1mo + PT 4Xwk, 1 mo</td>
<td>PT only, 4X/wk, 1 mo</td>
</tr>
<tr>
<td></td>
<td>Lee 2014&lt;sup&gt;16&lt;/sup&gt;</td>
<td>21</td>
<td>--</td>
<td>+</td>
<td>Augmented visual input during postural training (sit/stand); 3X/wk, 1 mo + PT, 5X/wk, 1 mo</td>
<td>PT only, 5X/wk, 1 mo</td>
</tr>
<tr>
<td></td>
<td>Park 2013&lt;sup&gt;15&lt;/sup&gt;</td>
<td>16</td>
<td>--</td>
<td>O</td>
<td>VR supine, sit, stand, 3X/wk, 1mo + PT 5X/wk, 1mo</td>
<td>PT only, 5X/wk, 1 mo</td>
</tr>
<tr>
<td></td>
<td>Yom 2015&lt;sup&gt;16&lt;/sup&gt;</td>
<td>20</td>
<td>--</td>
<td>+</td>
<td>Standing ankle exercise with VR; 5x/wk, 6 wks, 30-min sessions; + conventional PT</td>
<td>Watched documentary; 5x/wk, 6 wks, 30-min sessions; + b conventional PT</td>
</tr>
<tr>
<td>VR-balance vs</td>
<td>Chung 2014&lt;sup&gt;18&lt;/sup&gt;</td>
<td>19</td>
<td>--</td>
<td>+</td>
<td>Core stabilization with VR, 5X/wk, 6 wks</td>
<td>Core stabilization without VR, 5X/wk, 6 wks</td>
</tr>
<tr>
<td>other</td>
<td>Gil-Gomez 2011&lt;sup&gt;21&lt;/sup&gt;</td>
<td>17</td>
<td>O</td>
<td>O</td>
<td>Wii sitting and dynamic standing, 20 sessions</td>
<td>PT – balance activities, 20 sessions</td>
</tr>
<tr>
<td></td>
<td>Llorens 2015&lt;sup&gt;19&lt;/sup&gt;</td>
<td>20</td>
<td>--</td>
<td>+</td>
<td>30 min VR dynamic standing + PT, 5X/wk, 20 sessions</td>
<td>PT standing, stepping, walking, 5X/wk, 20 sessions</td>
</tr>
<tr>
<td></td>
<td>Song 2015&lt;sup&gt;20&lt;/sup&gt;</td>
<td>40</td>
<td>--</td>
<td>O</td>
<td>VR-X-box dynamic standing, 5X wk, 2 mo</td>
<td>Cycle ergometer, &lt;40% HR reserve, 5X wk, 2 mo</td>
</tr>
<tr>
<td>other</td>
<td>Fritz, 2013&lt;sup&gt;22&lt;/sup&gt;</td>
<td>30</td>
<td>O</td>
<td>O</td>
<td>Wii + standing balance training, no supervision, 5X/wk, 1 mo</td>
<td>No intervention</td>
</tr>
</tbody>
</table>
Appendix Table 3: Cycling and recumbent stepping

<table>
<thead>
<tr>
<th>Article</th>
<th>Level (score)</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bang 2016125</td>
<td>2 (9)</td>
<td>CVA</td>
<td>12</td>
<td>+</td>
<td>+</td>
<td>Cycling, 50-80% HRmax, 30 min, 5x/wk, 4wks + conventional PT</td>
<td>Cycling, self-selected speed, 30 min, 5x/wk, 4wks + conventional PT</td>
</tr>
<tr>
<td>Jin 2012127</td>
<td>1 (10)</td>
<td>CVA</td>
<td>133</td>
<td>+</td>
<td>+</td>
<td>Cycling, 50-70% HR reserve, 40 min, 5x/wk, 8 wks + balance and stretching</td>
<td>Cycling, 20-30% HRR, 40 min, 5x/wk, 8 wks + balance/ stretching</td>
</tr>
<tr>
<td>Jin 2013126</td>
<td>2 (9)</td>
<td>CVA</td>
<td>128</td>
<td>+</td>
<td>+</td>
<td>Cycling, 50-70% HR reserve, 40 min, 5x/wk, 12 wks</td>
<td>Conventional PT, 40 min, 5x/wk, 12 wks</td>
</tr>
<tr>
<td>Severinsen 2014149</td>
<td>1 (14)</td>
<td>CVA</td>
<td>43</td>
<td>O</td>
<td>O</td>
<td>Cycling, 75% HR reserve, 60 min, 3x/wk, 12 wks</td>
<td>2 groups: high intensity LE strengthening or sham UE training, 60 min, 3x/wk, 12 wks</td>
</tr>
<tr>
<td>Song 2015120</td>
<td>2 (5)</td>
<td>CVA</td>
<td>40</td>
<td>--</td>
<td>O</td>
<td>Cycle ergometer, &lt;40% HR reserve, 5x/wk, 2 mo</td>
<td>VR-X-box dynamic standing, 5X wk, 2 mo</td>
</tr>
</tbody>
</table>
## Appendix Table 4: Circuit and combined training

<table>
<thead>
<tr>
<th>Article</th>
<th>Level (score)</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Circuit training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dean 2000 (^{131})</td>
<td>1 (10)</td>
<td>CVA</td>
<td>12</td>
<td>+</td>
<td>+</td>
<td>Balance, strength, walking, no intensity, 3X/wk-1mo</td>
<td>UE exercise class</td>
</tr>
<tr>
<td>Moore 2016 (^{134})</td>
<td>1 (16)</td>
<td>CVA</td>
<td>40</td>
<td>+</td>
<td>+</td>
<td>Balance, strength aerobic &lt;80% HRR, 3x/wk-4 mo.</td>
<td>no intervention</td>
</tr>
<tr>
<td>Mudge 2009 (^{132})</td>
<td>1 (16)</td>
<td>CVA</td>
<td>60</td>
<td>+</td>
<td>O</td>
<td>Balance, strength, walking, no intensity 3x/wk;1 mo.</td>
<td>no intervention</td>
</tr>
<tr>
<td>Pang 2005 (^{133})</td>
<td>1 (17)</td>
<td>CVA</td>
<td>63</td>
<td>+</td>
<td>--</td>
<td>Balance, strength aerobic &lt;80% HRR; 3x/wk, 4 mo.</td>
<td>UE intervention</td>
</tr>
<tr>
<td>Song 2015 (^{136})</td>
<td>2 (6)</td>
<td>CVA</td>
<td>30</td>
<td>+</td>
<td>+</td>
<td>Balance, strength no intensity; 5x/wk, 1 mo + PT</td>
<td>PT only</td>
</tr>
<tr>
<td>Vahlberg 2016 (^{135})</td>
<td>1 (12)</td>
<td>CVA</td>
<td>43</td>
<td>+</td>
<td>--</td>
<td>Balance/strength/walking/cycling RPE &lt;17, 2X/w, 3 mo.</td>
<td>no intervention</td>
</tr>
<tr>
<td><strong>Combined training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hui-Chan 2009 (^{130})</td>
<td>1 (11)</td>
<td>CVA</td>
<td>109</td>
<td>--</td>
<td>+</td>
<td>Balance, strength, walking no intensity, 5X/wk-1mo</td>
<td>no intervention</td>
</tr>
<tr>
<td>Lee 2015 (^{137})</td>
<td>1 (10)</td>
<td>CVA</td>
<td>26</td>
<td>+</td>
<td>+</td>
<td>Strength, aerobic &lt;70% HRR, 3X/week-4mo.</td>
<td>no intervention</td>
</tr>
<tr>
<td>Tang 2014 (^{138})</td>
<td>1 (10)</td>
<td>CVA</td>
<td>50</td>
<td>--</td>
<td>O</td>
<td>Balance, strength aerobic &lt;80% HRR, 3x/wk-6 mo.</td>
<td>balance, flexibility, low intensity, same schedule</td>
</tr>
</tbody>
</table>
### Appendix Table 5: Locomotor training – aerobic walking

<table>
<thead>
<tr>
<th>Article</th>
<th>Level</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globas 2012&lt;sup&gt;[144]&lt;/sup&gt;</td>
<td>1 (15)</td>
<td>CVA</td>
<td>38</td>
<td>+</td>
<td>+</td>
<td>TM, 60-80% HRR, 3x/wk, 3mo</td>
<td>Passive stretch, balance</td>
</tr>
<tr>
<td>Gordon 2013&lt;sup&gt;[147]&lt;/sup&gt;</td>
<td>1 (14)</td>
<td>CVA</td>
<td>128</td>
<td>+</td>
<td>--</td>
<td>OG walking, 60-85% HRmax, 3x/wk, 12 wks</td>
<td>Light massage</td>
</tr>
<tr>
<td>Luft 2008&lt;sup&gt;[39]&lt;/sup&gt;</td>
<td>1 (13)</td>
<td>CVA</td>
<td>71</td>
<td>+</td>
<td>O</td>
<td>TM, 40 min, 60-80% HR reserve, 3x/wk, 6mo</td>
<td>Passive stretch</td>
</tr>
<tr>
<td>Moore 2010&lt;sup&gt;[2]&lt;/sup&gt;</td>
<td>1 (13)</td>
<td>CVA</td>
<td>20</td>
<td>O</td>
<td>O</td>
<td>TM, 80-85%HRmax, 20x/wk, 4 wks</td>
<td>no intervention</td>
</tr>
<tr>
<td>Macko 2005&lt;sup&gt;[32]&lt;/sup&gt;</td>
<td>1 (12)</td>
<td>CVA</td>
<td>61</td>
<td>+</td>
<td>O</td>
<td>TM, 60-80 HR reserve, 40 min, 3x/wk, 6mo</td>
<td>Low intensity, 30-40% HR reserve, stretch</td>
</tr>
<tr>
<td>Boyne 2016&lt;sup&gt;[148]&lt;/sup&gt;</td>
<td>1 (18)</td>
<td>CVA</td>
<td>18</td>
<td>O</td>
<td>+</td>
<td>TM, HIIT(30 s max, &lt;60 s rec) 3x/wk, 4 wks</td>
<td>TM, 45% HR reserve, 3x/week, 4 wks</td>
</tr>
<tr>
<td>Holleran 2015&lt;sup&gt;[49]&lt;/sup&gt;</td>
<td>1 (12)</td>
<td>CVA</td>
<td>12</td>
<td>+</td>
<td>O</td>
<td>TM&amp;OG, 30min, 70-80% HR reserve, 3x/wk, 4 wks</td>
<td>TM&amp;OG, 30min, 30-40% HRR, 3x/wk, 4 wks</td>
</tr>
<tr>
<td>Ivey 2015&lt;sup&gt;[51]&lt;/sup&gt;</td>
<td>1 (11)</td>
<td>CVA</td>
<td>34</td>
<td>O</td>
<td>O</td>
<td>TM, 30 min, 80-85% HR reserve, 3x/wk, 6mo</td>
<td>TM, 30 min, &lt;50% HR reserve, 3x/wk, 6mo</td>
</tr>
<tr>
<td>Munari 2016&lt;sup&gt;[50]&lt;/sup&gt;</td>
<td>1 (16)</td>
<td>CVA</td>
<td>16</td>
<td>+</td>
<td>+</td>
<td>TM, HIIT 1 min ints; 85% Vo2pk, 3 min 50% Vo2pk, 3x /wk, 3mo</td>
<td>TM, 50-60 min, 40-60% VO2 peak, , 3x /wk, 3mo</td>
</tr>
<tr>
<td>Yang 2014&lt;sup&gt;[52]&lt;/sup&gt;</td>
<td>1 (12)</td>
<td>SCI</td>
<td>22</td>
<td>+</td>
<td>O</td>
<td>TM, 60min, 5x/wk, 2mo, faster than SSV</td>
<td>precision training OG 5x/wk, 2mo</td>
</tr>
<tr>
<td>Awad 2016&lt;sup&gt;[53]&lt;/sup&gt;</td>
<td>1 (13)</td>
<td>CVA</td>
<td>50</td>
<td>O</td>
<td>O</td>
<td>TM&amp;OG, Fastest speed 40min, 3x/wk, 12 wks</td>
<td>TM&amp;OG, SSV40mi, n, 3x/wk, 12 wks</td>
</tr>
<tr>
<td>Sullivan 2002&lt;sup&gt;[30]&lt;/sup&gt;</td>
<td>1 (11)</td>
<td>CVA</td>
<td>24</td>
<td>--</td>
<td>O</td>
<td>TM, 2.0mph, 20 min, 12 sessions over 4-5 wks</td>
<td>TM, 0.5mph, 20 min, 12 sessions over 4-5 wks</td>
</tr>
</tbody>
</table>
Appendix Table 6: Locomotor Training: body-weight supported treadmill walking

<table>
<thead>
<tr>
<th>Article</th>
<th>Level</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexeeva 2011162</td>
<td>1 (12)</td>
<td>SCI</td>
<td>35</td>
<td>--</td>
<td>O</td>
<td>TM, 30% BWS, 3x/week, 60 min, 13 weeks, SSV</td>
<td>2 groups – conventional PT &amp; OG</td>
</tr>
<tr>
<td>Brown 2005163</td>
<td>2 (7)</td>
<td>TBI</td>
<td>20</td>
<td>O</td>
<td>O</td>
<td>TM, 30% BWS, 2x/wk, 14 wks +30 min exercise, 1-3 PT asst kinematics</td>
<td>OG, 2x/wk, 14 wks + 30 min exercise</td>
</tr>
<tr>
<td>Combs-Miller 2014164</td>
<td>1 (15)</td>
<td>CVA</td>
<td>20</td>
<td>O</td>
<td>O*</td>
<td>TM, 30% BWS, 5x/wk, 2 wks, PT asst kinematics</td>
<td>OG walking, 5x/wk, 2 wks, walk fast, not to exceed mod intensity</td>
</tr>
<tr>
<td>Middleton 2014164</td>
<td>1 (11)</td>
<td>CVA</td>
<td>43</td>
<td>O</td>
<td>O</td>
<td>TM, &lt;50% BWS, 10days, PT asst kinematics + 2 hrs balance, strength, ROM, coordination</td>
<td>OG walking, 60 min, 10days, + 2 hrs balance, strength, ROM, coordination</td>
</tr>
<tr>
<td>Suputtitada 2004165</td>
<td>2 (7)</td>
<td>CVA</td>
<td>48</td>
<td>--</td>
<td>O</td>
<td>TM, 30% BWS decr, 5x/wk, 4 wks, 0.44 m/s, increased as tolerated, 2 PT assist</td>
<td>OG walking, 15 min, 5x/week, 4 weeks</td>
</tr>
<tr>
<td>Lucarelli 2011166</td>
<td>2 (7)</td>
<td>SCI</td>
<td>30</td>
<td>--</td>
<td>O**</td>
<td>TM, 40% BWS decr, 2x/wk, 30 sessions, SSV, 2 PT asst kinematics + strength/ROM</td>
<td>OG walking, 2x/wk, 30 sessions, SSV, + stretching/ROM</td>
</tr>
<tr>
<td>Ribeiro 2013167</td>
<td>1 (10)</td>
<td>CVA</td>
<td>23</td>
<td>--</td>
<td>O</td>
<td>TM, 30% BWS, 3x/wk, 4 wks, 2 PTs asst kinematics, BWS decr &lt; PT assist needed, SSV</td>
<td>PNF, 3x/week, 30 min, 4 weeks</td>
</tr>
<tr>
<td>Yen 2008169</td>
<td>1 (10)</td>
<td>CVA</td>
<td>14</td>
<td>--</td>
<td>+</td>
<td>TM &lt;40% BWS, 3x/wk, 4 wks, 1-2 PTs asst kinematics, + 2-5x/wk general PT</td>
<td>2-5x/wk general PT</td>
</tr>
<tr>
<td>Takao, 2015168</td>
<td>1 (11)</td>
<td>CVA</td>
<td>18</td>
<td>--</td>
<td>+</td>
<td>TM, 20% BWS, 3x/week, 4 weeks, fastest possible speed</td>
<td>no intervention</td>
</tr>
</tbody>
</table>

*results favored the control (comparison) condition
**authors indicate difference without direct comparisons of treatment groups
## Appendix Table 7: Locomotor Training – robotic-assisted walking

<table>
<thead>
<tr>
<th>Article</th>
<th>Level</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bang 2016</td>
<td>1 (11)</td>
<td>CVA</td>
<td>18</td>
<td>--</td>
<td>+</td>
<td>Lokomat 45% BWS, 60 min, 5x/wk, 4 wks, incr from 0.45 m/s</td>
<td>TM, no BWS, 60 min, 5x/wk, 4 wks, speed incr 10%/sess</td>
</tr>
<tr>
<td>Buesing 2015</td>
<td>1 (14)</td>
<td>CVA</td>
<td>50</td>
<td>--</td>
<td>O</td>
<td>OG with hip assist device, 45 min, 3x/wk, 6-8 wks, variable walking, 75% HRmax</td>
<td>OG, 45 min, 3x/week, 6-8 weeks, variable walking, 75% HRmax</td>
</tr>
<tr>
<td>Esquenazi 2013</td>
<td>2 (9)</td>
<td>TBI</td>
<td>16</td>
<td>O</td>
<td>O</td>
<td>Lokomat, 10-20% BWS, 45 min, 3x/wk, 6 wks</td>
<td>TM, 10-20% BWS, PT assist, 45 min, 3x/wk, 6 wks</td>
</tr>
<tr>
<td>Field-Fote 2011</td>
<td>1 (12)</td>
<td>SCI</td>
<td>74</td>
<td>O*</td>
<td>O</td>
<td>Lokomat, &lt;30% BWS, 5x/wk, 12 wks, goal of 13 on RPE scale</td>
<td>3 groups; BWSTT, OG + e-stim, TM + e-stim, all &lt;30% BWS, 5x/wk, 12 wk</td>
</tr>
<tr>
<td>Hornby 2008</td>
<td>1 (13)</td>
<td>CVA</td>
<td>48</td>
<td>O</td>
<td>O*</td>
<td>Lokomat, &lt;30-40% BWS, 30 min, 3x/wk, 4 wks</td>
<td>&lt;30-40% BWS, PT assist as needed, 30 min, 3x/wk, 4 wks</td>
</tr>
<tr>
<td>Peurala 2005</td>
<td>1 (11)</td>
<td>CVA</td>
<td>45</td>
<td>O</td>
<td>O</td>
<td>Gait Trainer, 20% BWS, 20 min, 5x/wk, 4 wks, + regular PT</td>
<td>2 groups; robot+FES, OG walking; 20 min, 5x/wk, 4 wks, + regular PT</td>
</tr>
<tr>
<td>Westlake 2009</td>
<td>1 (14)</td>
<td>CVA</td>
<td>16</td>
<td>O</td>
<td>O</td>
<td>Lokomat, 35% BWS, 2 groups ( &lt; 0.69, &gt; 0.83 m/s, 30 min, 3x/wk, 4 wks)</td>
<td>BWSTT, 35%BWS, 30 min, 3x/wk, 4 wks</td>
</tr>
<tr>
<td>Stein 2014</td>
<td>1 (14)</td>
<td>CVA</td>
<td>24</td>
<td>O</td>
<td>O</td>
<td>Powered knee orthosis during walking, 50 min, 3x/wk, 6 wks</td>
<td>Group exercise, stretch light walking, matched duration</td>
</tr>
<tr>
<td>Ucar 2014</td>
<td>2 (9)</td>
<td>CVA</td>
<td>22</td>
<td>--</td>
<td>+</td>
<td>Lokomat, 50% BWS, 30 min, 5x/wk, 2 wks</td>
<td>ROM, strength, balance, gait, 30 min, 5x/wk, 2 wks</td>
</tr>
<tr>
<td>Forrester 2016</td>
<td>2 (9)</td>
<td>CVA</td>
<td>26</td>
<td>--</td>
<td>O</td>
<td>Ankle robot during TM, 60 min, 3x/wk, 6 wks</td>
<td>Seated ankle robot exercises, 60 min, 3x/week, 6 weeks</td>
</tr>
<tr>
<td>Labruyère 2014</td>
<td>1 (10)</td>
<td>SCI</td>
<td>9</td>
<td>--</td>
<td>O*</td>
<td>Lokomat, 30% BWS, 45 min, 4x/wk, 4 wks</td>
<td>Lower extremity strengthening, 45 min, 4x/wk, 4 wks</td>
</tr>
<tr>
<td>Lam 2015</td>
<td>1 (15)</td>
<td>SCI</td>
<td>15</td>
<td>O</td>
<td>O</td>
<td>Lokomat with resistance, BWS, 45 min, 3x/week, 3mo</td>
<td>Lokomat with assistance, BWS, 45 min, 3x/week, 3mo</td>
</tr>
<tr>
<td>Wu 2014</td>
<td>2 (9)</td>
<td>CVA</td>
<td>30</td>
<td>O</td>
<td>O</td>
<td>Cable swing resist during TM, 45 min, 3x/wk, 6 wks</td>
<td>Cable swing assist during TM, 45 min, 3x/wk, 6 wks</td>
</tr>
<tr>
<td>Wu 2016</td>
<td>2 (12)</td>
<td>SCI</td>
<td>14</td>
<td>O</td>
<td>O</td>
<td>Cable swing resist during TM, 45 min (35 TM, 10 OG), 3x/wk, 6 wks</td>
<td>Cable swing assist during TM, 45 min (35 TM, 10 OG), 3x/wk, 6 wks</td>
</tr>
<tr>
<td>Wu 2012</td>
<td>2 (9)</td>
<td>SCI</td>
<td>10</td>
<td>O</td>
<td>O</td>
<td>Cable swing resistance during TM, 45 min, 3x/wk, 4 wks</td>
<td>Cable swing assist during TM, 45 min, 3x/wk, 4 wks</td>
</tr>
</tbody>
</table>

137
Appendix Table 8: Locomotor Training – augmented feedback/virtual reality

<table>
<thead>
<tr>
<th>Article</th>
<th>Level</th>
<th>Dx</th>
<th>N</th>
<th>6 MWT</th>
<th>10 MWT</th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cho 2013\textsuperscript{195}</td>
<td>1 (12)</td>
<td>CVA</td>
<td>18</td>
<td>--</td>
<td>+</td>
<td>VR+TM, 30 min, 3x/wk, 6 wks + 30 min PT, 30 min FES, VR-community scenes</td>
<td>TM, 30 min, 3x/week, 6 weeks + 30 min PT, 30 min FES</td>
</tr>
<tr>
<td>Cho 2014\textsuperscript{196}</td>
<td>1 (13)</td>
<td>CVA</td>
<td>50</td>
<td>--</td>
<td>+</td>
<td>VR+TM, 30 min, 3x/wk, 6 wks + 30 min PT, 30 min FES, VR-community based scenes</td>
<td>TM, 30 min, 3x/wk, 6 wks + 30 min OT, 30 min PT, 30 min FES.</td>
</tr>
<tr>
<td>Kang 2012\textsuperscript{198}</td>
<td>1 (10)</td>
<td>CVA</td>
<td>16</td>
<td>+</td>
<td>+</td>
<td>VR+TM, 30 min, 3x/wk, 4 wks + PT, VR- path between trees</td>
<td>2 control groups: TM or stretch, 30 min, 3x/wk, 4 wks + PT</td>
</tr>
<tr>
<td>Kim 2015\textsuperscript{199}</td>
<td>2 (9)</td>
<td>CVA</td>
<td>74</td>
<td>--</td>
<td>+</td>
<td>VR +TM, 30 min, 3x/wk, 4 wks. VR-grocery shopping scenes</td>
<td>VR +TM, 30 min, 3x/wk, 4 wks.</td>
</tr>
<tr>
<td>Yang 2008\textsuperscript{197}</td>
<td>1 (11)</td>
<td>CVA</td>
<td>48</td>
<td>--</td>
<td>+</td>
<td>VR +TM, 20 min, 3x/wk, 3 wks. VR-community based scenes</td>
<td>TM, 20 min, 3x/wk, 3 wks</td>
</tr>
<tr>
<td>Cho 2015\textsuperscript{200}</td>
<td>1 (14)</td>
<td>CVA</td>
<td>45</td>
<td>--</td>
<td>O</td>
<td>VR+TM + cognitive tasks, 30 min, 5x/wk, 4wks + 30 min PT</td>
<td>VR+TM, 30 min, 5x/week, 4weeks + 30 min PT</td>
</tr>
<tr>
<td>Jaffe 2004\textsuperscript{202}</td>
<td>2 (9)</td>
<td>CVA</td>
<td>16</td>
<td>O</td>
<td>+</td>
<td>VR+TM+60 min, 3x/wk, 2 wks. VR-stepping over virtual objects</td>
<td>OG walking over obstacles, 60 min, 3x/wk, 2 wks.</td>
</tr>
<tr>
<td>Kim 2016\textsuperscript{201}</td>
<td>2 (8)</td>
<td>CVA</td>
<td>24</td>
<td>O</td>
<td>--</td>
<td>VR+TM, 30 min, 3x/wk, 4 wks. VR-overground, sidewalk, uphill and stepping over obstacles.</td>
<td>2 groups: usual PT or comm walking (outside, stairs, slopes, unstable surfaces) 30 min, 3x/wk, 4 wks</td>
</tr>
</tbody>
</table>