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Current Recommendations for Lower Body Aerobic Exercise in Chronic Unilateral Stroke - A Systematic Review

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CURRENT RECOMMENDATIONS FOR LOWER BODY AEROBIC EXERCISE IN CHRONIC UNILATERAL STROKE – A SYSTEMATIC REVIEW.

by

JORDAN BROWN

(Under the Direction of Nicholas Siekirk)

ABSTRACT

Background: Chronic stroke patients (i.e., ≥ six months since the onset of stroke) continue to experience persistent gait complications. Once formal physical therapy concludes, exercise professionals can implement exercise interventions designed to improve quality of life and reduce risk of secondary stroke. This systematic review aimed to evaluate whether lower-body aerobic exercise transferred to gait improvements in chronic unilateral stroke. Methods: An electronic search of the following databases were undertaken: MEDLINE, CINHAL, Ovid, and SPORTdiscus. Two independent reviewers selected articles using predetermined inclusion criteria: adults (i.e., ≥18 years old) who suffered from a chronic unilateral stroke. Additionally, all included studies were longitudinal exercise interventions (i.e., ≥ four weeks) of lower-body aerobic training with pre- and post- intervention assessments of gait (e.g., field and laboratory measures). Results: A total of 19 studies were included. The three most common field measures utilized by researchers were six-minute walk test (68%), 10-meter walk test (42%), and Timed Up and Go (TUG) (31%). Treadmill intervention (n=12) improved gait field testing from 23.68% to 31.73%, while elliptical interventions (n=1) improved from 0.88% to 11.56% and cycling intervention(n=5) improved from 6.13% to 24.44%. The aquatic intervention (n=1) only performed the TUG with a 51.14% average improvement. Discussion: The results suggest that not all aerobic training modalities elicit the same improvements in gait field assessments. Conclusion: Gait improvements can occur following aerobic training; however, treadmill interventions produced greater averages of improvements in chronic unilateral stroke.

INDEX WORDS: Aerobic exercise, Chronic stroke, Gait, Exercise professional, Field assessments

CURRENT RECOMMENDATIONS FOR LOWER BODY AEROBIC EXERCISE IN CHRONIC UNILATERAL STROKE – A SYSTEMATIC REVIEW.

by

JORDAN BROWN

B.S., Georgia Southern University, 2019
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MASTER OF SCIENCE

CURRENT RECOMMENDATIONS FOR LOWER BODY AEROBIC EXERCISE IN CHRONIC UNILATERAL STROKE – A SYSTEMATIC REVIEW.

by

JORDAN BROWN

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Committee:	Greg Ryan Samuel Wilson Ronald Snarr

Electronic Version Approved:
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DEDICATION

Daddy,

I may not have been able to help you when you suffered a stroke,

but now I can help others in your honor.

Forever grateful to have you as my angel, guiding me each and every day.

Love,

Boo girl

ACKNOWLEDGMENTS

Thank you to my advisor and the chair of my committee, Dr. Nick J. Siekirk: Working under you for the past two years has taught me a lot from research, to the world of academia, to life lessons. You have been a great mentor that listens and helps wherever is needed. Thank you for guiding me and helping me make a small impact in stroke research. I am grateful for and will always cherish the time spent working with you.

Thank you to my committee members and graduate professors: Dr. Wilson, Dr. Ryan and Dr. Snarr, from first year graduate classes to my thesis committee, you all have guided me to where I am today. I will always appreciate the time everyone took to work with me one on one, to help me improve upon my work and show me the impact that my work can make.

My family and friends: Thank you for supporting me every step of the way. I am not sure where I would be without the unconditional love and patience every single one of you provided me.

Thank you, Georgia Southern University. You have been my home for the past six years. These past six years have shaped me into the woman I am today. Thank you for bringing amazing professors and peers into my life. I will forever be proud to be a Georgia Southern Eagle.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

Strokes occur when neuronal blood supply is compromised, and the brain is deprived of necessary oxygen and nutrients. According to the National Institute of Neurological Disorders and Stroke, nearly 800,000 Americans suffer from strokes each year. Two-thirds require rehabilitation following the event (National Institute of Neurological Disorders and Stroke, 2020). Stroke is a leading cause of disability among adults due to the commonality of gait impairments that persists after the event (Dobkin & Dorsch, 2013; National Institute of Neurological Disorders and Stroke, 2020). Additionally, there is conflicting research on the acute, subacute, and chronic phases of a stroke. The terminology “acute stroke" is often used to describe the period immediately after the onset of a stroke through the first 15 days or up to 30 days following the initial onset (Ammann et al., 2014; Van Delden et al., 2012). Given the varying timeframe of acute stroke, it leaves uncertainty regarding the timeline of subacute stroke. The term “subacute phase” occurs after the acute phase ends (i.e., 15 – 30 day following onset of stroke) and is carried on until six months when the chronic phase begins (e.g., beginning at 15- 30 days until six months is reached) (Ammann et al., 2014; Van Delden et al., 2012). Regardless of the varying definitions of the early phases of the stroke, six months or greater since the stroke's onset is most commonly deemed the chronic phase (Ammann et al., 2014; Van Delden et al., 2012).

Despite structured acute and subacute rehabilitation programs, chronic stroke patients continue to experience residual gait asymmetries (e.g., stride length, stance time) and slowed gait speeds (e.g., 0.23 m/s – 0.73 m/s) (Olney & Richards, 1996). After a stroke, the recovery process is traditionally limited to the first 6-9 months after the onset of stroke because it was once thought that progress would start to plateau after three to four months (Dobkin, 2005). However, research has shown that a chronic stroke population can benefit from a structured exercise programs (e.g., improved aerobic fitness, increased strength, and increased functional capacity) even after the 9-month window (Bonita & Beaglehole, 1988; Claflin Krishnan, & Khot, 2015; Wolf et al., 2006). Specifically, 40-60% of stroke patients will regain their functional independence over time (i.e., three months to 10 years) (Hankey et al., 2007). After three weeks of gait rehabilitation, a chronic stroke population can see advances in walking independence through increased gait speed and improved dynamic balance (Peurala et al., 2005).

An individual's risk for a stroke is typically separated by two factors: unmodifiable (e.g., age, sex, ethnicity, genetics) and modifiable (e.g., blood pressure, lifestyle, cholesterol levels, heart disease). Additionally, stroke survivors are at an increased risk of another stroke occurring. Within the first year of stroke, patients are at a 5-14% increased risk of a secondary stroke, which increases to 25-40% within five years after the onset of stroke (National Stroke Association, 2010). Thus, the need for exercise and rehabilitation is extended far beyond the acute and subacute phases of recovery. Insurance companies or federal aid programs (e.g., Medicare and Medicaid) have restrictions that could stop the coverage of rehabilitation when the stroke survivor plateaus during their recovery processor have reached the maximum number of visits covered in their plan (AHCPR, 1995). With this being said, most patients will not get the full rehabilitation that may be required for recovery or to reduce modifiable risk factors of a second stroke.

How this study is original

Although there have been guidelines for acute and subacute rehabilitation for individuals, there remains uncertainty about chronic stroke rehabilitation. Variations in recovery are case-specific, spanning from rapid, early progression to late, rapid recoveries, while others experience slow, speedier recoveries (Hankey et al., 2002). Thus, this systematic review aims to evaluate various modalities of lower-body aerobic exercise for the rehabilitation of gait in chronic unilateral stroke. This systematic review examined the following questions:

1. What is the effect of a longitudinal aerobic intervention on gait?
2. What are the most common lower-body aerobic modalities of rehabilitation of gait?
3. What are the most common assessments of gait with a focus on field testing?

CHAPTER 2

METHODS

A systematic review of the peer-reviewed literature was performed to identify aerobic exercise interventions and their effect on gait in chronic stroke patients. For this systematic review, chronic stroke was defined as six months or greater since the onset of stroke (Ammann, 2014; Bernhardt, 2017; Van Delden, 2012). This review followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Boolean Search Criteria

1. Chronic Stroke or Chronic Cerebrovascular Accident or Chronic CVA
2. Aerobic Exercise or Aerobic training or Cardiovascular Training
3. Gait or walking

Table 1. The Boolean Search Criteria were input into each database utilizing AND to separate each line (i.e., Line one AND line two AND line three)

Search Strategy

The following databases were electronically searched from December 2020 - January 2021 1) Ovid 2) Cumulative Index to Nursing and Allied Health Literature (CINAHL) 3) National Library of Medicine Database (MEDLINE) 4) SPORTdiscus. A Boolean search was created to represent 1) Chronic Stroke, 2) aerobic exercise 3) gait. Synonyms of these terms were also included in the search, which can be seen in Table 1.

Eligibility Criteria

Inclusion and exclusion criteria can be found in Table 2. Only peer-reviewed articles published in English were included. This systematic review examined adults (i.e., ≥18 years old) with a clinical diagnosis of a chronic, unilateral stroke. If chronic stroke data were reported separately in studies that included other populations (e.g., acute stroke, subacute stroke, other chronic illnesses), it was included in this review; however, if data was reported as a whole, the studies were excluded.

Study designs included in this review are randomized control trials, quasi-experimental and experimental designs, prospective studies, case studies, or case-series studies. Only peer-reviewed articles were searched across the four databases. Published protocols were excluded from this review because no participant data/results are provided; instead, authors published the protocol they planned on executing.

Participants

Reviewers included studies examining adults (i.e., ≥18 years old) with a clinical diagnosis of a unilateral stroke. Specifically, this systematic review analyzed chronic stroke (i.e., the onset of stroke occurred ≥ six months before the onset of stroke). Therefore, acute (i.e., onset to one month) and subacute (i.e., one month to six months) strokes were excluded. Furthermore, studies that included participants with bilateral strokes were excluded due to the stroke's non-specific origin and its impact on gait.

Type of interventions

Peurala et al. (2005) stated that walking independence improved following three weeks of gait training; therefore, this review examined longitudinal (i.e., > three weeks) exercise interventions of lower-body aerobic training to improve gait. Interventions can include overground walking, aerobic machines (i.e., treadmill, NuStep, ellipticals, and cycle ergometers), or aquatic training. Studies that were less than three weeks long or included a multi-modality training approach were excluded. Multi-modality was defined as chronic stroke groups performing aerobic intervention in addition to traditional physical therapy, functional training, resistance training, or balance training. These studies were excluded to ensure gait improvements were occurring solely from the aerobic intervention implementation and not another form of training or combination thereof. Studies with multi-modalities across multiple groups (e.g., aerobic training group and a separate resistance training group) were included because data was reported separately.

Types of outcome measures

Both laboratory and field assessments of gait were accepted for this review. Gait assessment had to be performed at baseline and post-intervention and had to be a physical assessment of gait. Therefore, assessments in the form of questionnaires (e.g., Rivermead Mobility Index) were excluded. Field measures of gait included, but were not limited to, 10-meter walk test (10MWT), six-minute walk test (6MWT), Timed up and Go (TUG) assessment. The 10MWT is used to assess fastest and comfortable gait speeds, the 6MWT is used to measure distance covered, and the TUG is used to measure a participant's fall risk and be related to improvements in gait parameters. Laboratory measures of gait included but were not limited to gait speed, stride length, step length, step time, step time asymmetry ratio, and step length asymmetry ratio. These measures are commonly assessed in the lab with equipment like GAITRite or motion capture systems.

Setting

There were no restrictions by type of setting.

Language

This systematic review was limited to articles published in English.

Selection Process

Two review authors independently screened titles and abstracts from the search results. After the initial sweep, full articles were obtained from titles and abstracts that meet the inclusion criteria. Review authors examined full-text articles and compared the studies to the inclusion criteria. All reasons for exclusion were recorded by review authors in two individual excel documents. All disagreements were discussed with authors /committee members.

Eligibility Criteria

	Inclusion Criteria	*Exclusion Criteria*
Population	Adults (i.e., ≥18 Years Old)	Children and Adolescents (i.e., < 18 Years Old)
Phase of Stroke	Chronic stroke: Six months or greater following the initial onset of the stroke	● Acute ● Subacute ● Bilateral
Intervention duration	A longitudinal (i.e., ≥ four weeks in duration) study that employed a lower body aerobic exercise	● Studies that used a multi-modality training approach for the same group (e.g., traditional therapy + aerobic intervention) ● Studies less than four-weeks
Outcomes	Field measure of gait: ● 10-meter walk test ● Six-minute walk test ● Timed Up and Go Lab assessments of gait: ● GAITRite Measures ○ Gait velocity ○ Symmetry ○ Step length ○ Stride length ● Motion Capture Systems *This is an overview; other assessments of gait were included	● Metabolic cost of walking ● Rivermead Gait index ○ Not a physical assessment of gait ● Assessments of dynamic balance
Language	English	Any other language

Table 2. Eligibility Criteria

CHAPTER 3

RESULTS

Study Selection

This systematic search resulted in a total of 849 articles between the four databases (Figure 1). Of this, 761 articles were excluded after the titles and abstracts were evaluated for inclusion against the predetermined criteria. Prior to the full-text review, 24 duplicates were removed across the four databases, leaving a total of 64 articles for full-text review. Fort-five articles were excluded for various reasons (i.e., populations other than stroke, multi-modality training interventions, acute studies, lacking gait outcomes, or no aerobic intervention). Finally, the search resulted in 19 studies included in this systematic review (Figure 1).

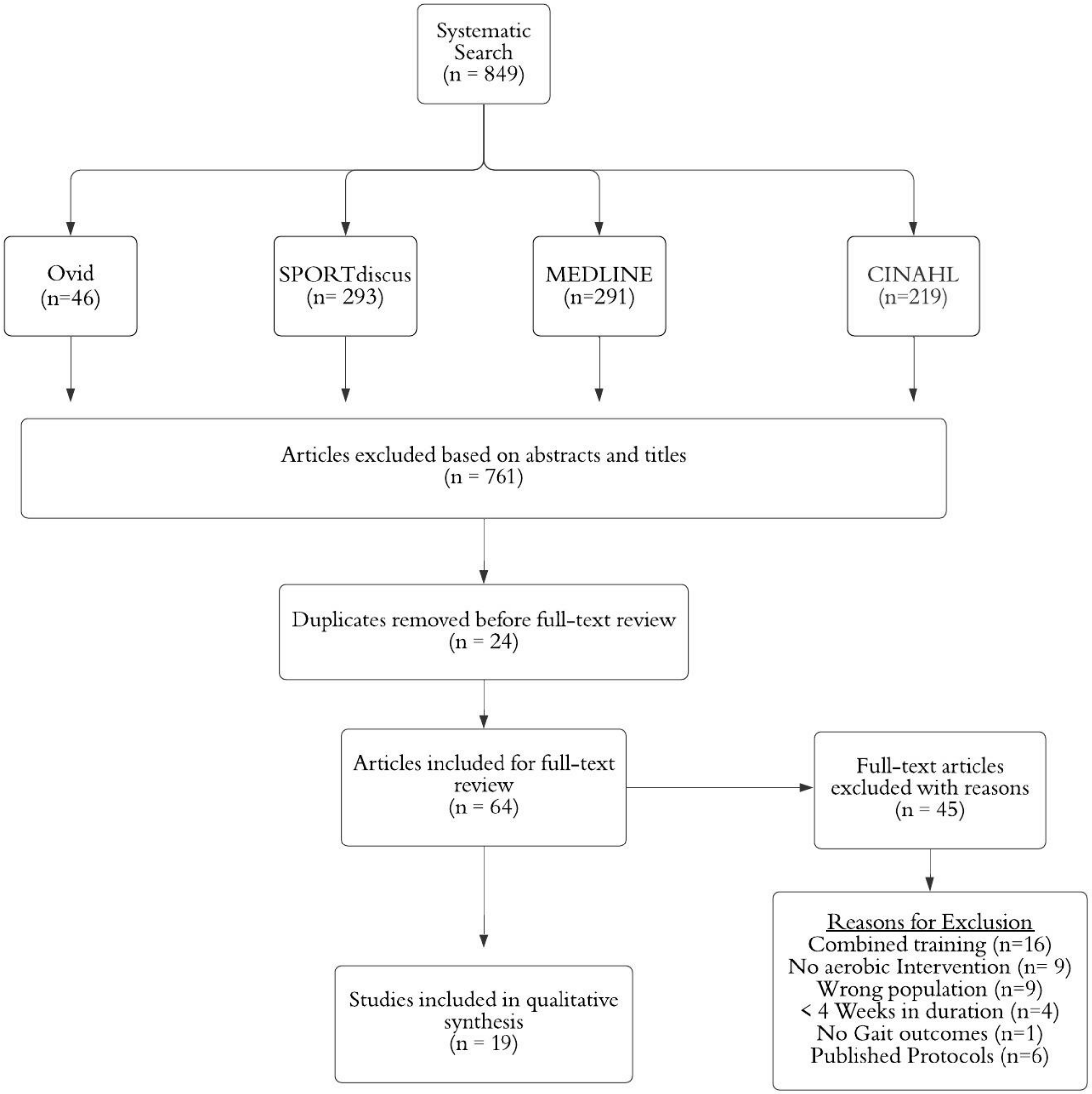

Figure 1. Flow Diagram

Study Characteristics

Of the included 19 studies, 63% (n=12) focused on treadmill interventions, 26% (n=5) on cycling interventions, 5.5% (n=1) on elliptical intervention and 5.5% (n=1) on aquatic training. In the included studies, treadmill interventions utilized progressive training (i.e., increasing intensity and duration over the courses of the intervention) (n= 3), wearable devices (i.e., robotic assistive device, weighted skin guard, and functional electrical stimulation) (n=3), backward walking (n=1), treadmill training followed by overground walking (n=4), and treadmill running protocols (n=1). Similarly, of the included cycling intervention studies, researchers performed traditional progressive cycling protocols (n=3) and cycling with functional electrical stimulation (n=2). Lastly, other modality interventions included an aquatic intervention (n=1) and an elliptical intervention (n=1).

Included manuscripts contained an array of field and laboratory assessments. Field measures were commonly used to assess gait changes; of the included studies, 68% (n=13) performed the 6MWT, 42% (n=8) performed 10MWT, 31% (n=6) performed TUG, 10% (n=2) performed the Dynamic Gait Index and 21% (n=4) performed other forms of field testing (i.e., 30-ft walk test, 2-minute walk test, 25-meter sprint time, and running symmetry). Additionally, 53% (n=10) of the studies collected spatiotemporal gait measurements using laboratory equipment (e.g., GAITRite, Qualys, and GaitMatt II). It should be noted that multiple gait assessment measures were gathered and used in a single study; therefore, the percentages will not add up to 100%. In fact, of the included studies, 42% (n=8) performed three or more assessments of gait, 37% (n=7) performed two assessments of gait, and 21% (n=4) only performed one assessment of gait.

Table 3. Study Characteristics for Treadmill Interventions

Study	Participants	Duration	Intervention	Outcome Assessments	Author's conclusion
Ryan et al. (2020)	N= 37 (n= 21 Step length asymmetry intervention; n= 16 Stance time asymmetry intervention)	6-9 weeks; 2-3x per week (18 total sessions)	All participants walked for up to 20 minutes on a treadmill followed by 15 minutes of overground walking. The split-belt treadmill speed was changed (augment, minimize or not modify asymmetry) to target goals of intervention type. Therapists also provided verbal feedback to improve symmetry.	6MWT; spatiotemporal measurements of gait (gait asymmetry and gait speed via GAITRite)	Although improvements in gait outcomes were seen, the changes did not occur due to the changes in spatiotemporal asymmetry, nor did the findings in the laboratory translate to increased community activity.
Patterson et al. (2008)	N=39	Six months; 3x a week	Progressive treadmill walking: started with 10-20 minutes at low intensity (40-50% HRR). The duration was progressed 5 minutes every two weeks and the intensity were progressed 5 percent HRR every two weeks. Goal: 40 minutes at 60-70% HRR	Spatiotemporal measures of gait (Average velocity, cadence, and stride length; Step Length via GAITRite); 30-foot walk velocity; 6MWT	Progressive treadmill training elicits changed in spatial and temporal gait parameters, which contribute to increased velocity in chronic stroke participants.
Dawes et al. (2007)	N= 18	Four weeks; 3x per week; 20 minutes	Progressive treadmill walking with body weight supported between 0-30%. The goal was to reach two mph while maintaining symmetrical limb kinematics	Spatiotemporal measures of gait (via GAITRite); 10MWT; 2-min walk test	The corticospinal tract and stroke lesion have a weak correlation and appear to be less critical in the control of gait function or gait retraining response.
Lathan et al. (2015)	N=1	Four weeks; 4x a week; 1-hour sessions (16 total sessions)	Treadmill training followed by overground walking: 40 minutes of treadmill walking at 65-85% heart rate max. Followed by overground walking to equal 60 minutes. Bodyweight support was decreased from 50% to10% unweighted by week 4	Spatiotemporal measures of gait (Gait speed, stride length, step length, and stance time); TUG; 6MWT; 10MWT (fastest and comfortable gait speed)	Pressure controlled treadmill training is associated with improvements across the gait parameters, such as increased gait speed, stride length, and distance covered during a 6MWT
Holleran et al. (2015)	N= 12	four -weeks of training followed by a four-week washout period, then another four weeks of training (12 total sessions during each training block)	Treadmill training was completed at two different intensities; however, the same speed and duration were maintained. High intensity: 70-80% HRR (achieved by adding resistance, load) Low Intensity: 30-40% HRR Overground walking was completed at the corresponding HRR for the intensity for both training intensities.	Self-selected velocity and Fastest possible velocity (via Gait Mat II); 6MWT	This study showed significantly greater improvements in gait parameters following high-intensity training when compared to low-intensity training.
Lewek et al. (2012)	N= 2	Six weeks; 3x a week; 45–60-minute sessions (18 total sessions)	Treadmill training was performed for 20 minutes of walking with a gait feedback system. This was followed by 10-15 minutes of overground walking. Recovery was as needed. Participants were instructed to walk as quickly as possible but maintain 70-75% of the estimated Heart rate max.	Spatiotemporal measures of gait (Fastest gait speed; comfortable gait speed, Step Length Asymmetry Ratio; Stance Time Asymmetry Ratio via GAITRite)	Progressive treadmill training coupled with visual and proprioceptive feedback allowed participants to improve gait speed and spatiotemporal symmetry, exceeding previous literature.
Reisman et al. (2013)	N=13	12 weeks; 3x per week (36 total sessions)	Four treadmill bouts of 6 minutes each (24 minutes). FES was delivered to the dors- and plantar-flexors during the first, third, and fifth minute (maximize motor learning/ minimize fatigue). ~5 min bouts of rest were provided between walking sets. The last set included 3 min FES treadmill walking followed by 3 minutes of overground walking (no FES)	10MWT (fastest and comfortable gait speeds); 6MWT; TUG	The walking function of chronic stroke patients can improve; however, different parameters improve across a different time scale. For this specific study, gait speeds were improved after 36 sessions

Boyne et al. (2016)	N=26 (n=13 high intensity; n= 5 5 continuous aerobic training)	4 weeks; 3x per week; 25-minute sessions (12 total sessions)	Overall: 3-minute warm-up at 30-50% HRR, 20-minutes of training, 2-minute cool down at 30-50% HRR High-intensity group: 30-second bursts at the max safe speed alternated with 30-60 second recovery periods. (fastest speed tested through a steep ramp test after warm-up) Continuous exercise group: Continuous treadmill walking with speed adjusted to maintain 45- 50% HRR	10MWT (fastest and comfortable gait speed); 6MWT	HIT and MCT training is feasible and safe in chronic stroke. Outcome comparisons showed moderate-to-very large effect sizes.
Miller et al. (2008)	N=1	Eight weeks; 3x per week (23 total treatments)	Three bouts of running (to participants tolerance or 10-min max) 1.5 min warm-up (self-selected fast walking pace) --> 7.5 minutes of running (self-selected fast running pace--> 1 minute cool down Feedback was provided through visual and verbal cues (ex: increase left step length) 20% body weight supported (BWS) was optimal for the best running technique (preferred by the participant) Progressed by decreasing BWS and increasing speed and running time (till max)	25-m Sprint (assess running speed); 6MWT; Running step length ratio; Running Step Width	The implementation of an intensive and task-specific treadmill protocol resulted in an improved recreational running ability through gait parameters, strength gains, and endurance
Bang et al. (2016)	N=18 (n= 9 Robot-assisted gait training; n=9 Treadmill gait training	Four weeks; 5x per week; 1-hour sessions (20 total sessions)	The robot-assisted group trained using the Lokomat device and harness. Participants followed the Lokomat machine to minimize assistance provided by the machine. It started at 40% BWS. Training intensity was progressively increased TGT: 5 min warm-up --> 10s maximum speed followed by a rest period	Spatiotemporal measures of gait (via GAITRite)	Protocols that utilize robot-assistive training (i.e., Lokomat) may be more beneficial than a traditional treadmill approach when trying to improve walking ability, balance, and balance confidence
de Lima Gomes et al. (2017)	N= 13 (n= 7 treatment group; n=6 control group)	6 weeks; 2x per week (12 total sessions)	Treatment group: 20 minutes of treadmill walking with shin guard applied to the unaffected limb (1-3 kg) Control group: Conventional training	10MWT; TUG	The addition of weight to the non-affected limb during treadmill training can elicit improvements in gait speeds, motor function, and balance in orthostatic.
Kim et al. (2017)	N=30 (n=15 progressive body weight support treadmill backward walking training; n=15 Treadmill training)	Four weeks; 5x per week; 30-minute sessions	Backward walking: Bodyweight supported was progressively reduced while performing backward walking training. Speed was increased by 5% for the following training session. CG: Forward treadmill training with no BWS and speed and intensity were chosen based on subjects' comfort.	Spatiotemporal measures of gait (via OptoGait); 6MWT; Dynamic Gait Index	Temporospatial characteristics can be improved through the implementation of a progressive body weight-supported treadmill protocol

Table 3. Treadmill Study Characteristics. HRR: Heart Rate Reserve; 6MWT: Six-Minute Walk Test; 10MWT: 10-meter walk test; FES: Functional Electrical Stimulation; TUG: Timed Up and Go; AT: Aerobic Training; RT: Resistance Training; HIT: High-intensity training; MCT: Continuous aerobic training

Treadmill Interventions with overground walking

Lathan et al. (2015) studied the acute and long-term effects of a pressure-controlled treadmill on gait function on a single participant (Table 3). The participant in this case study increased distance covered during the 6MWT (152.4 m [Pre] vs. 280.4 m [Post] vs.321.2 m [1-month follow-up]), and decreased TUG (25.79 s [Pre] vs. 3.5 s [Post] vs. 12.66s [1-month follow-up]). A Qualysis motion capture system measured gait speed (0.34 ± 0.02 m/s [Pre] vs. 0.74 ± 0.12 m/s [Post] vs. 0.87 ± 0.004 m/s [1-month follow-up]) stride length (0.58 ±0.05 m [Pre] vs. 0.95 ± 0.09 m [Post] vs. 1.00 ± 0.10 m [1-month follow-up]), and cadence (35.07 ± 1.90 stride/min [Pre] vs. 49.68 ± 4.73 stride/min [Post] vs. 49.74 ± 1.02 stride/min [1-month follow-up]).

Holleran et al. (2015) used a cross-sectional approach to assess the effects of high (70-80% HRR) versus low (30-40%) intensity treadmill training followed by overground walking on gait parameters in chronic stroke participants (Table 3). Both the high intensity (HI) and low intensity (LI) training elicited changes in self-selected velocity (HI: 0.54 ± 0.28 m/s [Pre] vs. 0.60 ± 0.29 m/s [Post]) (LI: 0.55 ± 0.31 m/s [Pre] vs. 0.60 ± 0.32 m/s [Post]), and fastest velocity (HI: 0.67 ± 0.38 m/s [Pre] vs. 0.72 ± 0.38 m/s [Post]) (LI: 0.67 ± 0.41 m/s [Pre] vs. 0.73 ± 0.42 m/s [Post]). The 6MWT had greater improvements from the HI training (191 ± 93m [Pre] vs. 231 ±121 m [Post]) when compared to the LI (207 ± 123 m [Pre] vs. 213 ± 125 m [Post]).

Lewek et al. (2012) examined the long-term effects of treadmill training combined with proprioceptive and visual feedback on gait outcomes (i.e., step length and stance time asymmetries) (Table 3). The first participant was unable to walk without a large-based quad cane at pre-testing. However, post-intervention and follow-up testing were able to be performed with and without the support of a cane. Participant one improved step length symmetry with a cane (1.52 [pre] vs. 1.32 [Post] vs. 1.26 [Follow-up]) and made further improvements without a cane (1.52 [pre] vs. 1.18 [Post] vs. 1.18 [Follow-up]). Similarly, participant one improved comfortable gait speed with a cane (0.49 m/s [Pre] vs. 0.65 m/s [Post]) and was able to further improve this without a cane (0.49 m/s [Pre] vs. 0.84 m/s [Post]).

Participant two did not use a cane at all during pre-and post-testing and improve comfortable gait speed (1.02 m/s [Pre] vs.1.28 m/s [Post]); however, a slight decrease was observed at follow-up (1.22 m/s [Follow-up]). Similarly, participant two demonstrated small improvements, for instance, time asymmetry (1.11 [Pre] vs. 1.04 [Post]); however, this was not maintained at follow-up (1.08 [follow-up]). Participant two demonstrated symmetrical step lengths and pre-and post-testing.

Ryan et al. (2020) assessed the differences in gait outcomes when groups performed aerobic training on a split-belt treadmill that specifically targeted spatiotemporal gait symmetry (Table 3). The group that trained to improve step length symmetry, increased 6MWT (509.3 ± 387.0 ft [Pre] vs. 608.5 ± 392.5 ft. [Post], *d*= 1.14) and decreased step length asymmetry (0.636 ± 0.099 [Pre] vs. 0.590 ± 0.058 [Post], *d*= 0.71). The group that trained to improve stance time asymmetry also increased 6MWT (639.1 ± 310.9 ft [Pre] vs. 793.0 ± 366.0 ft [Post], *d*= 1.03), however, participants did not improve stance time asymmetry (0.551 ± 0.018 [Pre] vs. 0.548 ± 0.019 [Post], *d*= 0.31). No correlation was found between the improvements in 6MWT and spatiotemporal gait symmetry (*r*= -0.164, *r*= -0.075).

Treadmill Intervention with progressions

Patterson et al. (2008) examined a 6-month long treadmill training program to increase overground walking velocity (Table 3). At the end of the 6-month interventions significant changes were seen in the functional field tests 6MWT (227 ± 105 m [Pre] vs. 268 ± 111m [Post],) and the 30-foot walk velocity (0.64 ± 0.29 m/s [Pre] vs. 0.74± 0.29 m/s [Post]). Similarly, laboratory assessments measured on GAITRite such as cadence (81.0 ± 16.3 SPM[Pre] vs. 86.0 ±16.4 SPM[Post]) and stride length (78.4 ± 28.7 cm [Pre] vs. 87.0 ±30 cm [Post]) significantly increased. This intervention did not elicit significant changes in step length ratio (1.37 ± 0.79 [Pre] vs. 1.41 ±0.83 [Post]). Thus, the changes in gait speed can be attributed to the improvements in cadence and stride length rather than an improvement in the paretic and non-paretic sides' symmetry.

Dawes et al. (2007) assessed stroke lesions and the degree of interruption in the corticospinal tract, and the impact on the response to an intervention and gait function (Table 3). Following the intervention, improvements were seen in velocity (Median = 0.89 m/s [Pre] vs. Median= 1.01 m/s [Post], 2-Min walk (Median = 114.62m [Pre] vs. Median= 134.47m [Post]) and 10MWT s (Median= 9.44s [Pre] vs. Median = 8.47s [Post]). The authors conclude that at 6-months post-stroke, the overlap of the stroke lesion and the corticospinal tract showed similar correlation trends. However, none reached the pre-established corrected significance level. Stronger relationships were seen in temporal gait measurements over spatial gait measurements.

Boyne et al. (2016) investigated the feasibility of high intensity interval treadmill training (HIIT) compared to continuous aerobic treadmill training (MCT) in chronic stroke (Table 3). The HIIT group performed 30-second bursts of walking at maximum speed followed by 30-60 second rest periods (20 total minutes), while MCT performed 20-minutes of continuous exercise at 40-55% HRR. Data for both groups were reported with baseline measurements and within group change. HIIT improved in fastest 10MWT (0.77 ± 0.54 [Pre], 0.10 m/s [Change]), comfortable 10MWT (0.63 ± 0.48 [Pre], 0.10 m/s [Change]), and 6MWT (220 ± 153 m [Pre], 15 m [Change]). MTC demonstrated changed in fastest 10MWT (0.91 ± 0.46 [Pre], 0.01 m/s [Change]), comfortable 10MWT (0.76 ± 0.36 [Pre], 0.02 m/s [Change]), and 6MWT (247 ± 121 m [Pre], 15 m [Change]). When the difference in change was assessed (HIT change - MCT change), HIIT saw greater change in fastest 10MWT (0.08 m/s [change between groups], effect size = 1.44), comfortable 10MWT (0.08 m/s [change between groups], effect size = 1.27), and no difference in 6MWT (0 m [change between groups], effect size = 0).

Treadmill Intervention: Running

Miller et al. (2008) carried out a single-subject report to investigate the feasibility and effectiveness of a running treadmill intervention in a 38-year-old male diagnosed with chronic stroke (Table 3). The participant saw improvements in sprint speed (3.39±0.30 m/s [Pre]) vs. 3.81 ± 0.25 m/s

[Post]) vs. 4.08± 0.24 m/s [6-month follow-up]). A 42% improvement was seen in the 6MWT (574 m [Pre] vs. 815 m [Post]), however, distance covered decreased at follow-up (637m). An interesting finding was that the step length ratio decreased over the course of the intervention (1.02±0.07 [Pre] vs. 0.942 ±0.049 [Post] vs. 0.922±0.024 [6-month follow-up]).

Treadmill Intervention with Backward Walking

Kim et al. (2017) compared gait outcomes (e.g., 6MWT, gait speed, paretic step length) of progressive backward body weight supported treadmill training to conventional treadmill training (Table 3). The backwards gait training group improved in 6MWT (237.27 ± 48.12m [Pre] vs. 272.60 ± 48.64m [Post] vs. 279.87 ± 45.78m [Follow-up]), gait speed (0.74 ± 0.31 m/s [Pre] vs 0.92 ± 0.37 m/s [Post] vs. 0.98 ± 0.36 m/s [Follow-up]), paretic leg step length (40.95 ± 6.90cm [Pre] vs. 46.01 ± 8.32 cm [Post] vs. 49.76 ± 8.16 cm [Follow-up]) and dynamic gait index score (16.73 ± 2.69 [Pre] vs. 20.20 ± 2.11 [Post] vs. 21.13 ± 2.03 [Follow-up]). The tradition treadmill training group demonstrated similar improvements in 6MWT (237.07 ± 51.01m [Pre] vs. 262.33 ± 47.68m [Post] vs. 270.60 ± 45.58m [Follow-up]), gait speed (0.73 ± 0.25 m/s[Pre] vs. 0.80 ± 0.31m/s [Post] vs. 0.86 ± 0.36 m/s [Follow-up]), paretic step length (39.14 ± 5.37 cm[Pre] vs. 41.52 ± 5.86 cm [Post] vs. 43.53 ± 5.50 cm [Follow-up]) and dynamic gait index (16.53 ± 2.47 [Pre] vs. 18.67 ± 1.95 [Post] vs. 20.60 ± 1.96 [Follow-up]).

Treadmill interventions with wearable devices

Bang et al. (2016) compared the effects of two variations of training, robot-assisted gait training (RAGT) and treadmill gait training (TGT) (Table 3). The intervention resulted in statistically significant results between groups in the mean change in gait speed (RAGT: 0.16 ± 0.03 m/s vs. TGT: 0.09 ± 0.05, *d*= 1.64), mean change of cadence (RAGT: 5.38 ± 1.23 steps/min vs. TGT: 2.45 ±1.92 steps/min, *d*= 1.78), the mean change in step length (RAGT: 4.46 ± 1.09 cm vs. TGT: 2.73 ± 0.93 cm, *d*= 2.37).

Reisman et al. (2013) performed a functional electrical stimulation (FES) assisted treadmill intervention in assessing the time-course changes in gait function in chronic stroke participants (Table 3). The intervention showed improvements in gait speed measured through the 10MWT from (0.05 ± 0.17 m/s [Pre] vs. 0.61 ± 0.19 m/s [4-weeks] vs. 0.68 ± 0.22 m/s [12-weeks], $p < 0.01$ and $p < 0.05$, respectfully). Distance covered was measured through the 6MWT and showed improvements from baseline (214 ± 92m) to 4-weeks (264 ±107) and again at 12-weeks (304 ± 125m). Finally, TUG did not significantly improve between baseline (21.5 ± 8.9 s) and 4-weeks (20.1 ± 9.3 s) but did improve by post-intervention assessments (17.6 ± 6.8 s).

De Lima Gomes et al. (2017) examined how additional shank load (i.e., 1kg females; 3kg males) on the non-affected leg during treadmill training (i.e., six weeks; 2x per week; 20-minute sessions) may influence the performance of the 10-m walk and TUG (Table 3). The intervention did not result in a statistically different 10-meter walk gait time post-intervention or 45 days post: (Median = 13 [Pre] vs. Median = 12 [Post] vs. Median = 9 [45 days post]) nor TUG step count (Median = 24 [Pre] vs. Median = 20 [Post] vs. Median = 17 [45 days post]), respectively. However, the authors argued the mathematical reduction in gait time, although not statistically different, was supported by the treadmill intervention. Notably, the control group (i.e., identified as conventional treatment) did not see statistically significant changes in the TUG or 10-meter walk test post-intervention (Median = 13 [Pre] vs. Median = 12.3 [Post]). No data was reported for the control group 45-days post-intervention.

Table 4. Study Characteristics for Cycling Interventions					
Study	Participants	Duration	Intervention	Outcomes	Author's conclusion
Severinsen et al. (2014)	N=43 (n=13 in aerobic training (AT) group, n=14 Resistance training (RT), n=16 sham training)	12 weeks; 3x per week; 1-hour sessions	AT= 15 minutes of strenuous cycling at 75% of heart rate reserve. this was done three times during the 1-hour training session	6MWT; 10MWT (fastest velocity)	Improving aerobic capacity or muscular strength through task-specific training methods does not lead to improved ambulation.
Lund et al. (2017)	N=48 (n=17 in aerobic training (AT); n=14 RT; n=17 (RT of upper extremity)	12 weeks; 3x per week; 1-hour sessions	AT= performed three bouts of 12 minutes at 75% HRR and between a 14-16 on the Borg Scale. Each bout was followed by 5-10 minutes of rest	6MWT; 10MWT (fastest gait speed)	Progressive cycling and resistance training can improve walking and balance performance in chronic stroke. However, changes in balance and walking performance were not correlated. This suggests that improving balance is not needed for functional improvements.
Jin et al. (2013)	N= 142 (n= 65 cycling group; n=63 control group)	12 weeks; 5x per week; 40-minute sessions	Cycling Group: Training started at low intensity (40-50% HRR) for 10 - 20 minutes and increased by 5 minutes every two weeks as tolerated. HRR was progressed by 5% every two weeks. Pedaled for 6-10 minutes during each task, then provided a rest period. Control group: 35 minutes of stretching and 5 minutes of low intensity (20-30% HRR)	6MWT	Aerobic training on a cycle ergometer can improve heart rate recovery in chronic stroke. The findings demonstrate the underlying importance of autonomic modulation on cardiovascular adaptations to stroke exercise rehabilitation.
Alon et al. (2010)	N=10	24 total training sessions (programmed to last 31 minutes and 45 seconds)	Participants were instructed to try and keep the speed of pedaling as close to 60 RPM. FES was increased 10 minutes after the start of the session.	TUG (they refer to it as the Get Up and Go test); Spatiotemporal measurements (via GAITRite)	Motorized FES-assisted cycling is feasible and safe in chronic stroke populations and can provide an alternative to traditional rehabilitation methods.
Aaron et al. (2017)	N= 13	8 Weeks; 3x per week; 30-minute sessions (24 sessions)	Progressive cycling increased HRR from 40-50% to 70-80% HRR by 8 weeks. FES was used to stimulate quad if power output was not maintained	Spatiotemporal measures of gait (Self-selected walking Speed; Fastest comfortable walking speed via GAITRite); 6MWT; Dynamic Gait Index	FES-assisted cycling can improve aerobic capacity and gait parameters in chronic stroke.

Table 4. Cycling Study Characteristics. HRR: Heart Rate Reserve; 6MWT: Six-Minute Walk Test; 10MWT: 10-meter walk test; FES: Functional Electrical Stimulation; TUG: Timed Up and Go; AT: Aerobic Training; RT: Resistance Training

Cycling with progression

Jin et al. (2013) investigated aerobic cycling intervention on heart rate recovery and cardiovascular fitness (Table 4). In this study, the experimental group cycled at 50-70% of HRR while the control group performed conventional therapy that included stretching and low intensity (20-30% HRR) overground walking. The cycling group saw a 2.9% improvement in 6MWT (212.5 ± 64.2m [Pre] vs. 219.4 ± 64.3m [Post]), whereas the control group only saw a 0.6% improvement (212.4 ±51.1m [Pre] vs. 213.7 ± 51.7m [Post]).

Severinsen et al. (2014) compared the short- and long-term impacts of progressive aerobic training and resistance training on gait performance (Table 4). Although this study examines resistance training, the groups are reported separately, therefore for the purpose of this systematic review, only the data from the aerobic training group will be discussed. Data was reported at mean changes in outcome measures. From baseline to immediately post-intervention, the aerobic training group improved in the 6MWT (mean change = 19 m) and the 10MWT (mean change= 0.05 m/s). The aerobic training group was not able to maintain these improvements at follow-up in the 6MWT (mean change= -53 m) or the 10MWT (mean change= -0.19 m/s). Thus, this intervention improved walking abilities in the short term; however, in the absence of a continued intervention, improvements were lost at the 1-year follow-up.

Lund et al. (2017) examined the effects of aerobic exercise and resistance training on balance performance and its correlation with improved gait function (Table 4). This study had the same setup as Severinsen et al. (2014) with the aerobic training group report separately; thus, this will be the only group data reported. The aerobic training group experienced a 7.4% increase in gait speed from baseline (1.18 ± 0.49 m/s [Pre]) and a 9.6% increase in distance covered during the 6MWT (298 ± 125 m [Pre]).

Cycling with Functional Electrical Stimulation

Aaron et al. (2017) investigated the feasibility and the impact of FES assisted recumbent cycling on locomotor function (Table 4). Improvements were seen in self-selected walking speed (0.35 ± 0.2 m/s

[Pre] vs. 0.40 ± 0.2 m/s [Post]) and dynamic gait index (11.18 ± 3.7 [Pre] vs. 12.82 ± 4.0 [Post}, however no change in fastest walking speed (0.51 ± 0.3 m/s [Pre] vs. 0.51 ± 0.3 m/s [Post]) or 6MWT (456.27 ± 288.2 ft [Pre] vs. 492.05 ± 343.8 ft [Post]) was observed. Furthermore, self-selected walking speed had a strong positive correlation with a change in 6MWT (*r* = 0.74).

Alon et al. (2010) explored an intensive combined motorized cycling with FES cycling intervention on locomotion variables (Table 4). Improvements were seen in the TUG (45.0 ± 54.9 sec [Pre] vs. 34.0 ± 31.8 [Post]), gait velocity (0.4 ± 0.3 m/s [Pre] vs. 0.5 ± 0.4 [Post]), cadence (61.5 ± 26.5 spm [Pre] vs. 65.4 ± 30.3 spm [Post]) and single limb stance time (0.33 ± 0.14 sec [Pre] vs. 0.40 ± 0.06 sec [Post]). It should be noted that the researchers stated the feasibility study limitations were not including all possible factors that contribute to improved walking function.

Aquatic Intervention with a Treadmill Control Group

Franciulli et al. (2019) examined the impact of aerobic aquatic training compared to treadmill training on gait and balance in chronic stroke (Table 5). The time it took to complete the TUG assessment decreased for both groups; however, the aquatic training (26.67 ± 14.65 s [Pre] vs. 13.03 ± 7.52 s [Post]) and the treadmill training (19.00 ± 2.37 s [Pre] vs. 16.67 ± 1.86 s [Post]) did not differ between groups.

Elliptical Intervention

Jackson et al. (2010) looked at the feasibility of using a non-motorized elliptical intervention to improve functional gait in chronic stroke (Table 5). Data was reported at percent differences (%diff). Participant 1 experienced small improvements in fastest gait speed (1.21 m/s [Pre] vs. 1.24 m/s [Post], %diff = 2%), 6MWT (345m [Pre] vs. 349m [Post], %diff = 1), and TUG (14.2 s [Pre] vs. 13.5 s [Post], %diff = -5), however decreased in habitual gait speed (0.98 m/s [Pre] vs. 0.92 m/s[Post], %diff = -6).

Table 5. Study Characteristics for Other Modality Interventions

Study	Modality	Participants	Duration	Intervention	Gait Outcome Variables	Author's Conclusion
Jackson et al. (2010)	Non-motorized Elliptical Training	N=3	Eight weeks; 2-3x per week (Completed: 20, 20, & 11 training sessions)	50-55 RPM on the elliptical (maintaining 75% HRR). The goal was to achieve 20 minutes of uninterrupted elliptical training. Once participants reached 20 minutes (while keeping training parameters), the resistance of the machine was increased. A harness was used for safety purposes, and as training progressed, it assisted in postural control as participants fatigued.	10MWT (Habitual and Fastest Gait Speed); 6MWT; TUG	Although elliptical training was a safe and feasible training modality for chronic stroke, however, the duration of training (2-3x per week) did not elicit changes in gait speed.
Franciulli et al. (2019)	Aquatic vs. Treadmill Training	N=12 (n=6 pool; n=6 treadmill)	Nine weeks; 3x per week; 40-minute sessions	5 min warm-up (overground walking) --> 30 minutes for conditioning (pool or treadmill) --> cool down (overground walking) 1st week: Adaptation Phase (40-50% HRmax) 2nd - 9th week: overload phase (60% HRmax)	TUG	Either training intervention (i.e., aquatic or treadmill) can lead to similar improvements in balance and gait; however, the muscular activity will differ in the chronic stroke participants.

Table 5. Other modality Study Characteristics. HRR: Heart Rate Reserve; 6MWT: Six-Minute Walk Test; 10MWT: 10-meter walk test; TUG: Timed Up and Go

Participant 2 experienced small improvements in fastest gait speed (1.05 m/s [Pre] vs. 1.08 m/s [Post], %diff = 3%), 6MWT (322 m [Pre] vs. 328 m [Post], %diff = 2%), and TUG (16.0 s [Pre] vs. 13.7 s [Post], %diff = -15) and habitual gait speed 0.86 m/s [Pre] vs. 0.91 m/s [Post], %diff = 6). Participant 3 saw similar improvements in fastest gait speed (0.39 m/s [Pre] vs. 0.41 m/s [Post], %diff = 5), 6MWT (102 m [Pre] vs. 128 m [Post], %diff = 25), and TUG (28.6 s [Pre] vs. 24.2 s [Post], %diff = -15) and habitual gait speed 0.34 m/s [Pre] vs. 0.35 m/s [Post]).

Table 6 Exercise Mode Calculated Percent Change

Study	Gait Measure	Percent Mean Change [%STDΔ(Low) - %STDΔ(High)]
Treadmill		
Lanthan et al. (2016)	6MWT	83.99
	TUG	-47.65
	10MWT (Comfortable)	92
	10MWT (Fastest)	82.19
	Gait Velocity	117.65 [93.75-138.89]
	Stride Length	63.79 [62.26- 65.08]
	Cadence	41.66 [35.51-47.17]
Holleran et al. (2015)	Gait Velocity (comfortable)	High intensity: 11.11 [8.54 – 19.23] Low intensity: 9.09 [6.98 – 16.67]
	Gait Velocity (Fastest)	High intensity: 7.46 [4.76 – 17.24] Low intensity: 8.96 [6.48 – 19.23]
	6MWT	High intensity: 20.94 [12.24 – 23.94] Low intensity: 2.90 [2.42 – 4.76]
Lewek et al. (2015)	Step Length Asymmetry	Participant 1: -13.19
	Gait Velocity (comfortable)	Participant 1: 71.43 Participant 2: 25.49
	Stance Time Asymmetry	Participant 2: -6.31
Ryan et al. (2020)	6MWT	Step length symmetry: 19.48 [11.68 – 76.61] Stance time symmetry: 24.08 [22.00 – 30.10]
	Step Length Asymmetry	Step length symmetry: -7.23 [-11.84 - -0.93]
	Stance Time Asymmetry	Stance time symmetry: -0.54 [-0.75 - -0.35]
Patterson et al. (2008)	6MWT	18.06 [14.16 – 28.69]
	30-ft Walk Velocity (Comfortable)	15.63 [10.75 – 28.57]
	Cadence	6.17 [5.24-7.57]
	Step Length Ratio	2.92 [0.00 – 3.70]
Dawes et al. (2007)	Velocity	13.48
	2-Minute walk Test	17.32
	10MWT (measured in seconds)	-10.28
Boyne et al. (2016)	10MWT (Fastest)	HIIT: 12.99 MCT: 0.00
	10MWT (Comfortable)	HIIT: 15.87 MCT: 2.63
	6MWT	HIIT: 6.82 MCT: 6.07

Miller et al. (2008)	Sprint Speed	12.39 [10.03 – 15.21]
	6MWT	41.99
	Step Length Ratio	-765 [-9.08 - -6.00].
Kim et al. (2017)	6MWT	Backward Gait: 14.89 [12.56 – 18.40] Traditional: 10.66 [7.61-15.37]
	Gait Speed	Backward Gait: 24.32 [22.86 – 27.91] Traditional: 9.59 [2.08- 13.27]
	Paretic Step Length	Backward Gait: 12.36 [10.69 – 13.54] Traditional: 6.08 [5.60 – 6.45]
	Dynamic Gait Index	Backward Gait: 20.74 [14.88 – 28.85] Traditional: 12.95 [8.53 – 18.92]
Bang et al. (2016)	Gait Speed	No percentages (data was reported as mean change)
	Cadence	No percentages (data was reported as mean change)
	Step Length	No percentages (data was reported as mean change)
Reisman et al. (2013)	10MWT (comfortable)	36.00 [34.33- 39.39]
	6MWT	42.06 [40.20- 46.72]
	TUG	-18.14 [-19.74 - -14.29]
de Lima Gomes et al. (2017)	TUG	The group with Shin guard: Conventional:
	10MWT	
Cycling		
Jin et al. (2013)	6MWT	Cycling: 3.25 [2.53 – 4.59] Control: 0.61 [0.43 – 0.72]
Serverinsen et al. (2014)	6MWT	AT: 6.07
	10MWT (fastest)	AT: 6.17
Lund et al. (2017)	6MWT	AT: 9.60
	10MWT (Fastest)	AT: 7.40
Aaron et al. (2017)	Gait Velocity (comfortable)	14.29 [9.09 – 33.33]
	Gait Velocity (Fastest)	0.00
	Dynamic Gait Index	14.67 [13.04 – 17.91]
Alon et al. (2010)	TUG	-24.44 [-34.13 - -122.22]
	Gait Velocity	25.00 [0.00 – 28.57]
	Cadence	6.34 [0.29 – 8.75]
	Single Limb Stance Time	21.21 [-2.13 – 78.95)
Other Modality		
Franciulli et al. (2019)	TUG	Aquatic: -51.14 [-50.27- -54.16] Treadmill: -12.26 [-11.00 - -13.24]
Jackson et al. (2010)	10MWT (fastest)	P1: 2.48 P2: 2.86 P3: 5.13
	10MWT (comfortable)	P1: -6.12 P2: 5.81 P3: 2.94
	TUG	P1: -4.93 P2: -14.38 P3: -15.38
	6MWT	P1: 1.16 P2:1.86 P3: 25.49

Table 6. Exercise Mode Calculated Percent Change. 6MWT: Six-minute walk test; TUG: Timed Up and Go; 10MWT: 10-meter walk test.

Modality	6MWT	10MWT (Comfortable Speed)	10MWT (Fastest Speed)	TUG
Treadmill	24.33% (n =12 groups)	28.90% (n = 6 groups) *†	31.73% (n = 3 groups)*	23.68% (n = 4 groups)*†
Cycling	6.13% (n = 3 groups)†	--	6.79% (n = 2 groups)	24.44% (n = 1 group)
Aquatic	--	--	--	51.14% (n = 1 group)
Elliptical	9.50% (n = 3 groups)	0.88% (n = 3 groups)	3.49% (n = 3 groups)	11.56% (n = 3 groups)

Key:
*Control group reported
†Control group not reported
--Modality did include that fitness assessment

Table 7. Calculated Averages of Percent Improvement by Field Test

CHAPTER 4

DISCUSSION

This is the first systematic review that summarizes lower extremity aerobic interventions that target gait rehabilitation for individuals with chronic stroke to the best of our knowledge. It is essential to collectively understand the aerobic interventions studied to help individuals with chronic stroke feel comfortable when being discharged from rehabilitation. The chronic stroke phase is when the exercise professional can implement a program that will assist in improved gait parameters, which in turn leads to greater independence and quality of life and decreased risk of a secondary stroke (Jacobs, 2018). The results showed that treadmill and cycling-based interventions are the most commonly used modality for training chronic stroke individuals. Traditional treadmill and cycling training are often described as a continuous exercise that increases in intensity and duration over time as an individual improves. Aside from this, researchers have started to investigate the effects of backward walking, pressure-controlled treadmills, wearable devices, and high-intensity training. Although new approaches have been developed recently, there remains uncertainty if these new approaches yield better improvements compared to traditional methods.

This systematic review suggests that not all modalities elicit the same gait improvements in a chronic stroke population. Specifically, the participants in the elliptical intervention case study saw minimal improvements in gait outcomes. On the other hand, treadmill training has been shown to improve gait outcomes in chronic stroke. Although wearable devices (i.e., Lokomat, FES, or weighted shin guards), and A-typical treadmills (i.e., pressure-controlled treadmills or split-belt treadmills) might elicit greater improvements in gait when compared to traditional treadmill training, improvements can still be seen during traditional training (de Lima Gomez, 2017; Bang, 2016; Reisman, 2013; Lathan, 2015; Ryan, 2020). Therefore, in a chronic stroke population, the addition of wearable devices or pressure-controlled treadmills can help gait rehabilitation; however, it is not pertinent due to the lack of accessibility and expense. Even though protocols involving equipment that is not always accessible, other protocols demonstrated that cueing could help improve gait changes (Ryan, 2020, Lewek 2012).

Additionally, high-intensity training protocols can improve gait greater than low intensity or continuous exercise interventions (Boyne, 2016; Holleran, 2015). Lastly, the duration of the interventions has an impact on gait outcomes. Specifically, Reisman et al. (2013) stated the participants needed 36 sessions of their intervention to see improvements in gait velocity. Thus, different gait parameters will improve at different rates. Furthermore, when an aquatic intervention was compared to a treadmill intervention, researchers found improvements in the TUG; however, both group improvements did not differ. Similar to treadmill training, cycling interventions also demonstrated improvements in gait. Severinsen et al. (2014) found that improvements in aerobic capacity in chronic stroke patients do not automatically translate to improved walking ability. However, Aaron et al. (2017) found that FES-assisted cycling improved both aerobic capacity and gait parameters.

In this review, laboratory and field tests were analyzed to assess gait changes. The exercise professional can use field tests like the 6MWT, 10MWT, and TUG to assess baseline gait parameters prior to implementing an exercise program. Additionally, as seen in several of the studies, these tests can be administered at the end of programming to determine the training program's efficacy on gait performance.

Study Limitations

One limitation to this review was not assessing outcomes outside of the gait measures. Given the review's scope, aerobic interventions often looked at aerobic capacity as primary outcomes; however, this was not assessed when looking at gait outcomes of those studies (Jin, 2013; Franciulli, 2019). Thus, improvements in gait performance may be due to increased aerobic capacity rather than from task-specific training. Additionally, if gait was a secondary outcome, there might have only been one form of gait assessment (e.g., TUG or 6MWT). These assessments can be used for other purposes aside from gait improvement. TUG is a functional mobility test to assess fall risk; however, a decrease in time to complete the TUG can suggest an improvement in gait performance (i.e., gait speed).

Similarly, 6MWT can be used as a submaximal aerobic capacity assessment, however increasing the distance covered can also suggest improvement in gait performance (e.g., gait speed and gait symmetry). Another limitation to this study was not assessing all forms of aerobic exercise. The literature did not lend itself to newer forms of exercise modalities that are becoming more commonplace in the clinical setting (e.g., NuStep Recumbent Cross Trainer). Lastly, this review accepted case studies and case series with small sample sizes. Although they may not be sufficiently powered in a traditional experiment setting, they were included in this review because chronic stroke participants will typically be working one-on-one with a trainer or themselves. Thus, the case studies/case series results are still important and should be considered by the exercise professional when building a program for an individual with chronic stroke.

Future Research

This review excluded multi-modality training interventions; thus, future research should investigate gait changes when aerobic training is combined with other training forms (e.g., resistance training, functional training, and balance training). Two studies included in this review, Servivensen et al. (2014) and Lund et al. (2017), examined resistance training and aerobic exercise in the same study; however, groups remained separate. The aerobic training group experienced a more significant decrease in walking velocity at a 1-year follow-up than the resistance training group (Serverivensen, 2014). When programming, exercise professionals create programs that address both aerobic and resistance training; thus, it would be warranted to perform a systematic review looking at the short-and long-term effects of combined resistance and aerobic exercise intervention on gait changes.

CHAPTER 5

CONCLUSION

This systematic review suggests that not all gait training modalities elicit the same improvements in gait function. Gait improvements can occur following aerobic training; however, treadmill interventions produced greater averages of improvements in chronic unilateral stroke. These studies suggest that higher intensities (60-80% HRR) are feasible and safe and improve ambulation in a chronic stroke population. It should be noted that access is limited to more advanced technology; however, improvements in walking function can be made without this equipment, even though greater improvements were made while using it.

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APPENDIX A

LITERATURE REVIEW

Stroke Prevalence

Research has estimated nearly 800,000 Americans suffer a stroke each year, of which two-thirds survive the stroke but require a form of rehabilitation (National Institute of Neurological Disorders and Stroke, 2020). Roughly, seven million Americans are living with complications from a stroke (Dobkin & Dorsch, 2013). Thus, stroke is the leading cause of disability in the united states (Dobkin & Dorsch, 2013). Additionally, stroke survivors are at an increased risk of a secondary stroke. Specifically, within the first year following a stroke, an individual is at a 5-14% increased risk. This risk continues to increase to 25-40% within the first five years (National Stroke Association, 2010).

Stroke Risk Factors

An individual's risk for a stroke is typically separated by two factors: unmodifiable (e.g., age, sex, ethnicity, genetics) and modifiable (e.g., blood pressure, lifestyle, cholesterol levels, heart disease). As an individual ages, the risk for a stroke is increased. At younger ages, men are more likely to suffer from a stroke than women to have a stroke. However, women tend to live longer. Women who take birth control pills or use hormone replacement therapy also develop an increased risk over time. Lastly, women are also at higher risk during pregnancy and in the weeks following giving birth. This occurs because women who developed high blood pressure (i.e., preeclampsia) during their pregnancy are at increased risk during and the few weeks following giving birth. Overall, women are at an overall increased lifetime risk of suffering from a stroke due to unmodifiable risk factors. Ethnicity is another unmodifiable risk factor. In the United States, stroke occurs more often in African American, Alaska Native, American Indian, and Hispanic adults than in white adults (National Stroke Association, 2010). On the other hand, there are risk factors that an individual can change to modify their risk of a stroke. A sedentary lifestyle paired with poor nutritional habits can lead to high cholesterol, high blood pressure, and heart disease, all of which can increase an individual's risk for a stroke.

Type of stroke

There are three main types of stroke—ischemic, hemorrhagic, and transient ischemic strokes. Ischemic strokes are the most common and account for roughly 80% of all strokes (Jacobs, 2018). This stroke occurs when blood flow is interrupted by a blood clot. This can be from a thrombosis (i.e., localized blood clot), embolism (i.e., a blood clot that travels to the brain from elsewhere in the body), or a global ischemic (i.e., blood flow to the entire brain is halted or drastically decreased) (Jacobs et al., 2018). The second stroke is a hemorrhagic stroke which typically accounts for 10-15% of all strokes. This type of stroke occurs when a blood vessel ruptures and leads to a brain bleed. Lastly, there is transient ischemic strokes which are only temporary and are usually referred to as "warning strokes" or "mini-strokes" because they are only temporary blockage of blood flow and resolve on their own (Jacobs et al., 2018). Name aside; these strokes still need to be taken seriously as they are a potential indicator of something bigger.

Phases of stroke

There is conflicting research on the acute, subacute, and chronic phases of a stroke. Acute stroke has been used to refer to the onset of a stroke through the first 15 days or up to 30 days after (Ammann et al., 2014; Van Delden et al., 2012).). Given the varying definition of acute stroke, it leaves uncertainty regarding subacute stroke timeline since there is not a set timeline. The subacute phase occurs after the acute phase ends and is carried on until six months when the chronic phase begins (e.g., beginning at 15-30 days until six months is reached) (Ammann et al., 2014; Van Delden et al., 2012).). Regardless of the inconsistency in the definitions of the early phases of the stroke, six months or greater since the onset of the stroke is most commonly deemed the chronic phase (Ammann et al., 2014; Van Delden et al., 2012).

Bernhart et al. (2017) took this a step further when the research team broke up a stroke phase into five phases. Specifically, they deemed the onset of stroke through the first 24 hours to be the hyper-acute phase, acute was defined at one to seven days, early subacute was seven days – three months, late subacute was three to six months. Finally, chronic was six months and beyond. Regardless of the addition of hyperacute, early subacute and late subacute, the definition of chronic has remained consistent.

The acute phase of rehabilitation is when the individual with a stroke is in the hospital or intensive care unit. This is when the patient gets visits from a variety of practitioners (e.g., physical therapists, neurologists, cardiologists, occupational therapists, and speech pathologists). The practitioners use those visits to assess daily life activities and start to build a rehabilitation program that will be carried out in the subacute phase (Dobkin, 2005; Dobkin & Dorsch, 2013). During the subacute phase, practitioners want to focus on regaining independence. Specifically, this is an intense form of rehabilitation that will assist the patient in daily life activities such as walking, self-care, and language skills (Dobkin & Dorsch, 2013). The chronic phase has less potential for improvements when compared to the subacute phase; however, this phase can improve the quality of life through specific goals (Dobkin, 2005). Given the broad timeframe of chronic stroke (i.e., $\geq$ 6 months), there will be fewer practitioners working with the patient; thus, there remains uncertainty with the forms of rehabilitation that utilized to make progress and improvements as well as assessable to a chronic stroke population.

Gait characteristics

Patients who have regained walking independence exhibit gait patterns that differ from those observed in healthy individuals (Balaban & Tok, 2014). Specifically, individuals that have suffered from a stroke often present with an asymmetric gait due to the stance phase on the affected leg being short and abrupt (Roth et al., 1997). Previous research has stated that swing time, stance time, and step length asymmetries appear to worsen in the later stage of stroke (Patterson et al., 2010). As these asymmetries worsen, they can be associated with an increased risk of falling (Balaban & Tok, 2014). The more extended stance phase and slowed gait occur due to diminished strength and limited power (Olney & Richard 1996).

Furthermore, the knee on the body's affected side may experience more flexion or hyperextension during the stance phase. This occurs because the person may seek stability and, in turn, demonstrate hyperextension compared to a non-disabled individual (Olney, 1996). Excessively flexion of the knee can occur to reduce the moment generation at the knee extensors, ankle plantar flexors, and hip extensors (Olney & Richard, 1996). Ambulation ability has been correlated with gait speed; thus, retraining gait is an essential goal for stroke persons (Olney & Richard, 1996; Perry et al., 1995).

Aerobic exercise

It is common for stroke patients to become decondition, which is seen through a peak oxygen consumption value roughly half of an age-matched control (Palmer-McLean & Harbst, 2003). Rehabilitative exercises can improve ambulation and reduce the risk of a secondary stroke in a chronic stroke population (Stoloff, Zehr & Ferris, 2007). Thus, it seems warranted to investigate aerobic exercise modalities that would improve ambulation in a chronic stroke population. Previous research has found the treadmill to be an effective way to improve gait because this modality increases walking pace and aerobic endurance (Macko et al., 2005). Similarly, research has found cycling to increase gait speeds and dynamic balance due to the reciprocal movement provided by the bilateral pedaling (Kim et al., 2015).

Field gait assessments

Field assessments are an easy way to assess fitness and health levels before implementing an intervention. When dealing with a chronic stroke population, the most common forms of field testing are the six-minute walk test (6MWT), Timed Up and Go (TUG), and the 10-meter walk test (10MWT). 6MWT is a test commonly used to assess aerobic capacity and gait. A participant is instructed to walk as far as they can in a 6-minute time frame, and the distance covered is measure in feet or meters. The main goal is to improve the distance covered in six minutes from pre to post-testing. This assessment has excellent test/ retest reliability for a chronic stroke population because it can be performed with or without assistive devices and remain reliable (Flansbjer et al., 2005; Fulk et al., 2008). Flansbjer et al., 2005 found it to have excellent concurrent validity with other field assessments (e.g., 10MWT and TUG) (Flansbjer et al., 2005). The 10MWT has an excellent test/ retest reliability for both comfortable and fastest gait speed assessments in a chronic stroke population (Flansbjer et al., 2005). Tyson & Connell in 2009 found that the 10MWT has a strong correlation with dependence in activities of daily living (r= 0.76) (Tyson & Connell, 2009). Lastly, TUG is a functional mobility assessment that can assess an individual's fall risk based on timed to complete the test. Strong relationships exist with TUG, 10MWT, and the 6MWT, and an excellent test/ retest reliability exists in a chronic stroke population (Flansbjer et al., 2005).

Issues with rehabilitation

Insurance companies or federal aid programs (e.g., Medicare and Medicaid) have restrictions that could stop rehabilitation coverage when stroke survivor plateaus during their recovery process (AHCPR, 1995). Furthermore, chronic stroke survivors can have persistent complications from a stroke long after being discharged from a practitioner's care. Therefore, exercise professionals need to know what modalities and interventions to implement with a chronic stroke population to provide a means of rehabilitation after physical therapy has ended.

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