



Cycling Interventions and Gait Speed in Older Adults: A Systematic Review of Exercise Prescription and Mobility Outcomes

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Abstract: Gait speed has become a key predictor in identifying individuals at risk for falls in both healthy and clinical populations. Given the cost of falls on the healthcare system and the aging population, decreasing the prevalence for falls and improving gait speed has become an important area of research for reducing the financial burden on the healthcare system. Cycling, in particular, has emerged as a promising modality to improve gait speed, with recent evidence suggesting that cycling cadence may be a key variable influencing this improvement. This systematic review aims to identify the current state of the literature regarding cycling cadence and gait speed, with seventeen studies meeting the inclusion criteria for inclusion in this review. Evidence generally supports the benefits of cycling interventions for improving gait speed, but also highlights inconsistencies in the reporting of cycling prescription variables including cadence, work rate, and intensity within the literature. Furthermore, the studies identified do not provide insight into potential underlying adaptations that may be driving the reported improvements in gait speed. Across the included studies, cycling interventions were generally associated with improvements in gait speed or related mobility outcomes across a range of older adult and clinical populations. Future studies should more consistently report cycling prescription variables and incorporate mechanistic outcomes to better understand how cycling interventions improve gait performance.

Keywords: Cycling, Gait, Cadence, Mobility.

1. Introduction

As the average age of the world's population continues to rise, the need for fall prevention guidelines in aging populations becomes increasingly important. Non-fatal fall related medical expenses totaled an estimated \$80 billion in 2020 (Haddad *et al.*, 2024), with an annual cost of emergency department visits totaling almost \$20 billion (Reider *et al.*, 2024) With a population of individuals over the age of 60 expected to reach 1.4 billion in 2030 and 2.1 billion by the year 2050 (World Health Organization, 2024), these estimated costs of fall related injuries are set to increase significantly over the coming decades. To combat these anticipated cost increases to accommodate an aging population, there is a significant need to reduce the prevalence of falls in

aging populations through improvement in identification of those at increased risk for falls and through improving our intervention selection to decrease fall risks in high-risk populations. While interventions targeting strength and balance to decrease risk for falls remain the standard of care for decreasing fall risk, walking as a standalone intervention has not demonstrated the same level of evidence for fall prevention (Avin *et al.*, 2015).

Of the outcome measures that have been used to identify individuals at increased risk for falls, gait speed consistently has been found to be strongly linked to multiple risk factors of aging in older populations, with one of these being fall risk (Leveille *et al.*, 2008). Specifically, gait speeds less than 1.0 meters per second



have been shown to be correlated to increased risk for falls (Kyrдалen *et al.*, 2019). Interventions targeted towards improving gait speed have focused on both an impairment-based approach and a task specific approach, with both demonstrating varying degrees of improvement in gait speed (Brach & VanSwearingen, 2013).

Non-ambulatory interventions, such as cycling, stretching, and tai chi have also demonstrated varying degrees of success in improving gait (Bean *et al.*, 2004; M. Brown & Holloszy, 1991; Wolf *et al.*, 2006). Cycling, in particular, has long been utilized as a training modality for improving gait outcomes in a variety of populations, from individuals with orthopedic issues such as knee osteoarthritis (Kline Mangione *et al.*, 1999; Salacinski *et al.*, 2012) to individuals with neurodegenerative disorders such as stroke (D. Brown *et al.*, 2005; D. A. Brown & Kautz, 1998) and Parkinson's disease (Linder *et al.*, 2022; Uygur *et al.*, 2015, 2017). Each of these studies provide theories as to the underlying mechanisms and adaptations that may be occurring to explain the improved gait outcomes seen following cycling interventions, with strength improvements and neuromuscular adaptations both being presented as possible explanations. Cycling has also been compared against elliptical training and treadmill walking to determine its effectiveness for improving gait parameters, with Damiano *et al.* concluding that, while effective, it was not superior to elliptical training or treadmill walking (Damiano *et al.*, 2011).

It has been suggested that the neuromuscular coordination between agonistic and antagonistic muscles required for pedaling has carryover to ambulation, positioning cycling as a viable intervention for improving gait (Raasch & Zajac, 1999). It has also been found that the neuromuscular strategies used in both cycling and ambulating are very similar, with over 90% of the variability in electromyography (EMG) signals being accounted for from only four muscle synergies that are shared between the two tasks (Barroso *et al.*, 2013). Cycling is additionally appealing due to its low-cost, low-equipment nature, and low safety risk for falls in a variety of at-risk populations.

There is a large variety in the application of cycling as an intervention on gait speed, with improvements in gait speed largely being presented as an ancillary benefit of cycling rather than a primary goal of the intervention. Additionally, there has not been much discussion in the literature to this point regarding the specific parameters of cycling that are responsible

for improvements in gait speed, with literature pointing both the possibility of strength and neural adaptations taking place, but little focus on what specifically about cycling is driving these adaptations. Early evidence suggests that it may be cycling cadence that is the variable primarily responsible for the acute adaptations seen in gait speed (Bellumori & Knight, n.d.; Keating *et al.*, 2024), while other evidence suggests it may be strength adaptations that are responsible for gait improvements (Perell *et al.*, 2001) or simply high intensity effort cycling (Linder *et al.*, 2022). The goal of this literature review is to review the current body of evidence investigating the effect of cycling cadence on gait speed.

2. Methods

2.1 Literature Search

This systematic review was registered through PROSPERO (ID: CRD42023387051) on May 12, 2022. To determine the current availability of evidence as it relates to cycling and gait performance, a systematic search was performed within the PubMed, SCOPUS, and Web of Science databases for articles ranging from January 1992 to December 2023 using the search terms "Cycling or Cycle Ergometer and Gait". A final search was performed on 09/15/2024. Searches were limited to English-language, peer-reviewed, human studies.

The original search strategy centered on the concepts of cycling and gait. Database specific search strings were adapted as needed for each platform. The exact search strings used were as follows:

PubMed:

("cycling"[Title/Abstract] OR "cycle ergometer"[Title/Abstract]) AND ("gait"Title/Abstract)

Scopus:

TITLE-ABS-KEY ("cycling" OR "cycle ergometer") AND TITLE-ABS-KEY ("gait") AND PUBYEAR > 1991 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE, "English"))

Web of Science:

TS = ("cycling" OR "cycle ergometer") AND TS = ("gait")

Timespan: 1992-2023; Language: English

This search yielded a total of 760 results with specific results of each database as follows: PubMed 378, SCOPUS 73, Web of Science 309. After removing

99 duplicate articles, the remaining 662 articles were screened for inclusion in this review.

related outcomes; however, these studies were not eligible for inclusion in this present review.

2.1.1 Eligibility Criteria

Articles were reviewed against inclusion criteria consisting of:

- Randomized controlled trials, clinical trials, or cross-sectional studies published in English in peer reviewed journals.
- Quantitative measures of cycling exposure or cycling intervention parameters
- Reported measurement of gait speed or gait-related mobility outcomes

Studies involving neurodegenerative conditions were excluded to reduce clinical heterogeneity and maintain focus on population in whom gait limitations were not primarily driven by progressive neurologic disease. Literature involving populations such as Parkinson’s disease and stroke is discussed in the Introduction to provide a broader clinical context regarding the historical use of cycling to influence gait-

2.1.2 Screening and Study Selection

Through this process a total of 610 articles were removed through abstract screening due to wrong population or study design, or not reporting cycling or gait parameters, leaving 52 potentially relevant papers that were sought for retrieval. An online web tool (Rayyan) was utilized for the abstract screening process which allowed for a blinded review of four independent reviewers with discrepancies being resolved by discussion between reviewers (Ouzzani *et al.*, 2016). Each author then reviewed the remaining studies independently and a consensus was reached regarding their eligibility with 15 final studies being identified as eligible for inclusion. Disagreements regarding study eligibility were resolved through discussion among the reviewers until consensus was reached. Two additional articles were identified through citation searching of the eligible studies and screened for inclusion resulting in 17 total studies being included in this review. See Figure 1 for full PRISMA guidelines for search criteria.

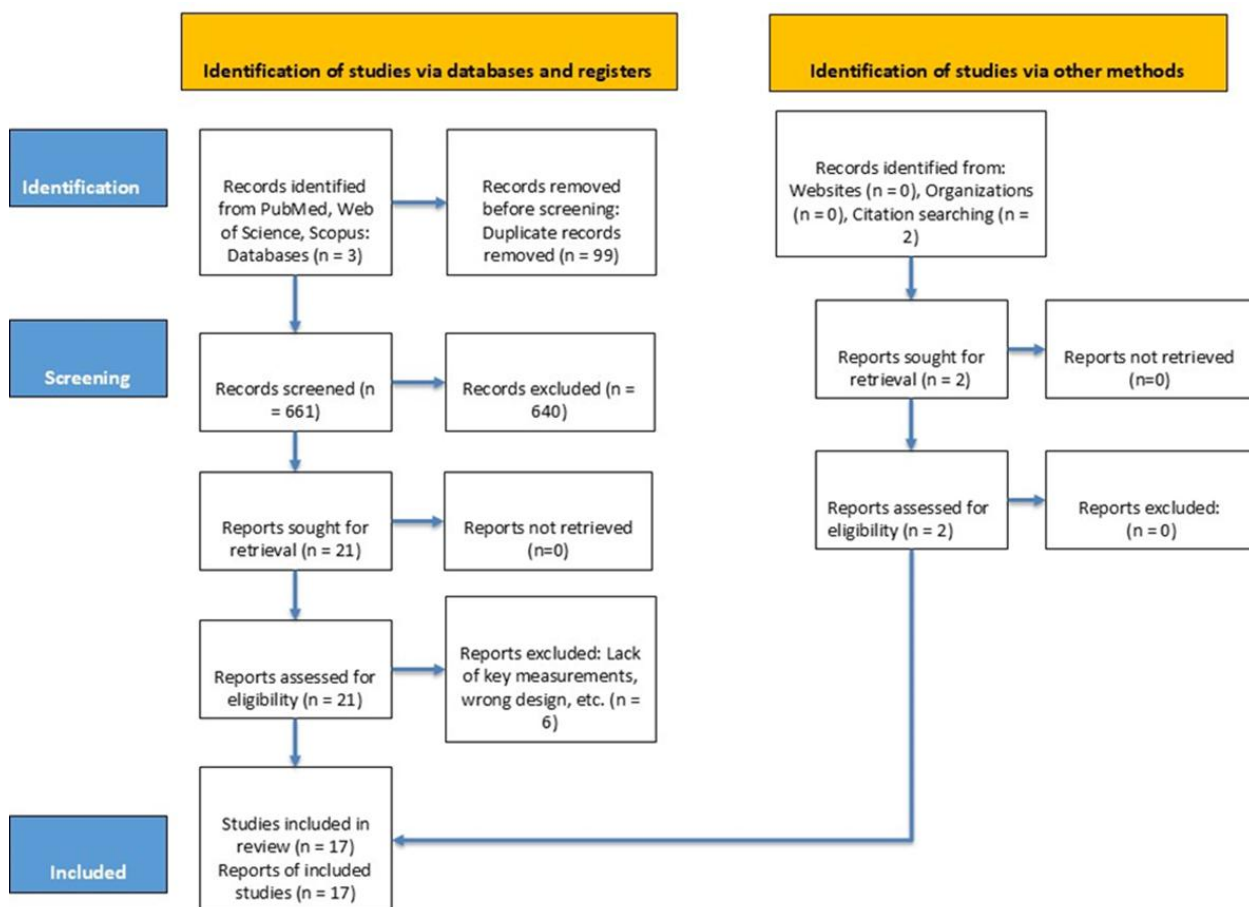


Figure 1. PRISMA 2020 Flow diagram

2.2 Quality Assessment and strength of evidence

To assess the quality of each included study, the Physiotherapy Evidence Database (PEDro) scale was utilized to score each study (de Morton, 2009). The PEDro scale ranks the quality of studies on an eleven point scale, with one point being awarded for each of the following: eligibility criteria is clearly specified, subjects were randomly allocated to groups, allocation was concealed, the groups were similar at baseline,

blinding of all subjects, blinding of those administering testing procedures, blinding of those measuring key outcomes, measures of at least one key outcome were obtained for >85% of subjects initially allocated to groups, all subjects for whom outcome measures were available received the treatment or control condition as allocated, the results of between-group statistical comparisons are reported for at least one key outcome, and the study provides both point measures and measures of variability for at least one key outcome.

Table 1. PEDro - Quality Assessment

Authors	Item 1*	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Total Score
Bellumori <i>et al.</i> 2017	1	1	0	1	0	0	0	1	1	1	1	6
Bogataj <i>et al.</i> 2023	1	1	0	1	0	0	0	0	1	1	1	5
Buchner <i>et al.</i> 1997	1	1	0	1	0	0	1	0	1	0	1	5
Harvey, Rissel, & Pijnappels 2018	1	1	0	1	0	0	0	0	0	1	1	4
Keogh <i>et al.</i> 2018	1	1	1	1	0	0	0	0	1	1	1	6
Koufaki <i>et al.</i> 2014*	1	1	1	1	0	0	0	0	0	1	1	5
Kline Mangione <i>et al.</i> 1999	1	1	0	1	0	0	1	1	0	1	1	6
Macaluso <i>et al.</i> 2003	1	0	0	1	0	0	0	1	1	1	1	5
Painter <i>et al.</i> 2000a*	1	0	0	1	0	0	0	1	1	1	1	5
Painter <i>et al.</i> 2000b*	1	0	0	0	0	0	0	0	1	1	1	3
Raso&D'Andrea Greve 2012*	1	1	0	1	0	0	0	1	1	1	1	6
Said <i>et al.</i> 2021	1	1	1	1	0	0	1	1	0	0	1	6
Salacinski <i>et al.</i> 2012	1	1	0	1	0	0	0	1	0	1	1	5
Sauvage <i>et al.</i> 1992	1	1	1	1	0	0	0	0	1	1	1	6
Tatemoto <i>et al.</i> 2019	1	1	0	1	0	0	0	1	1	1	1	6
Tollár <i>et al.</i> 2019	1	1	1	1	0	0	0	0	1	1	1	6
Veldema <i>et al.</i> 2019	1	1	1	1	0	0	0	0	1	1	1	6

▪ Scored by reviewers

* Not counted toward total score

The PEDro scale ranks studies into four categories: poor, fair, good, and excellent. Studies receiving 3 or fewer points on the PEDro scale are considered poor, those receiving 4-5 points are considered fair, with 6-8 points being considered good, while 8-10 points are considered excellent. When scoring using the PEDro scale, Item 1 which defines the eligibility criteria is not included in the scoring. See Table 1 for the complete PEDro scoring for each study. Data extraction was performed independently by the authors, and any discrepancies were resolved until consensus was reached. Outcomes extracted from each study include cycling parameters, including cadence, work rate, and intensity along with measurements of gait speed, both specific measurements of speed and those reported through functional testing such as treadmill walking speed or a Timed Up and Go (TUG) test.

3. Results

Of the 17 articles included, 14 of these studies were interventions, two examined acute bouts of cycling, and one cross-sectional study. Each of the 17 studies were published in the English language with 7 of the studies being conducted in the United States (Bellumori *et al.*, 2017; Bohannon, 1997; Buchner *et al.*, 1997; Kline Mangione *et al.*, 1999; Painter *et al.*, 2000a, 2000b; Salacinski *et al.*, 2012; Sauvage Jr. *et al.*, 1992), 3 being conducted in Australia (Harvey *et al.*, 2018; Keogh *et al.*, 2018; Said *et al.*, 2021), two in the United Kingdom (Koufaki *et al.*, 2014; Macaluso *et al.*, 2003) and one each being performed in Brasil (Raso & D'Andrea Greve, 2012), Germany (Veldema *et al.*, 2019), Hungary (Tollár *et al.*, 2019), Japan (Tatemoto *et al.*, 2019), Slovenia (Bogataj *et al.*, 2023), and the United Kingdom (Koufaki *et al.*, 2014)

A total of 852 participants were included in this systematic review, with 15 of the 17 studies reporting gender; with 255 males and 431 females being analyzed in this review. The two studies that did not include gender accounted for over half of the total sample at 452 participants (Painter *et al.*, 2000a, 2000b). Of the participants in the study, the total average age is 65.4 ± 10.9 years, with only one study consisting of young adults (Tatemoto *et al.*, 2019), while the other sixteen were comprised of older adults, both healthy and unhealthy. Of the studies consisting of older adults, three were of healthy populations (Harvey *et al.*, 2018; Macaluso *et al.*, 2003; Raso & D'Andrea Greve, 2012), while three studies involved patients actively undergoing hemodialysis (Bogataj *et al.*, 2023; Painter

et al., 2000a, 2000b), three included populations with knee osteoarthritis (Keogh *et al.*, 2018; Kline Mangione *et al.*, 1999; Salacinski *et al.*, 2012), three sedentary populations (Bellumori *et al.*, 2017; Buchner *et al.*, 1997; Sauvage Jr. *et al.*, 1992), and one each of populations with heart failure (Koufaki *et al.*, 2014), recent hip fracture (Said *et al.*, 2021), recent intensive care unit (ICU) patients (Veldema *et al.*, 2019), and older adults with generalized mobility deficits (Tollár *et al.*, 2019). Table 2 provides a complete breakdown of participant characteristics for each study.

Fifteen of the seventeen included studies were interventional in nature, while one study was a single session to determine acute responses of cycling (Tatemoto *et al.*, 2019) and another being a cross-sectional design (Harvey *et al.*, 2018). The one acute bout study included in this review was performed by Tatemoto *et al.* (Tatemoto *et al.*, 2019), who recruited 11 healthy young adults to perform both skillful cycling and constant-speed cycling on two separate days to determine their effect on motor learning. The skillful cycling group was asked to control a cursor on a monitor at the bike by adjusting the revolutions at which they were pedaling, with a cycling cadence ranging between 20-60 RPMs, whereas the constant-speed group was asked to maintain a cycling cadence of 40 RPMs. Following electromyogram (EMG) recordings and transcranial magnetic stimulation (TMS) data collections, it was determined that the skillful cycling group demonstrated significantly improved motor performance over the constant-speed group.

The one cross-sectional study included in this review was performed by Harvey *et al.* (Harvey *et al.*, 2018) in which the authors compared the mobility, balance, endurance, gait speed, and muscular power of cyclists and non-cyclists. The authors found that there was a significant positive correlation between cycling and improved TUG and six-meter walk test. Cycling history was determined based on a questionnaire filled out by participants, with no cycling being performed as a part of the study.

Of the interventional studies, Bellumori *et al.* (Bellumori *et al.*, 2017) performed a cycling intervention of 2 bouts per week for 6 weeks, looking to determine the effects of high-speed cycling on gait speed measured with a TUG test, maximal elbow and knee isometric forces, and a 9-hole peg upper extremity dexterity test. Following the 6-week intervention with a post-intervention mean cycling cadence of 106 revolutions per minute (RPMs), a 23% increase in the post-intervention TUG scores for the high-speed cycling

group was reported, with no meaningful change reported in the control group.

Similarly, *Bogataj et al.* (*Bogataj et al.*, 2023) found an improved gait speed over the course of a 12-week intervention in patients undergoing hemodialysis treatments three times per week. Cycling cadence was not reported in this population, with the researchers instead having patient's cycle at an RPE of 4-5/10 on a modified Borg scale. Gait speed was reported in meters

per second, with the experimental group increasing their gait speed from 1.21 ± 0.19 m/s to 1.27 ± 0.14 m/s while the gait speed of the control group decreased over the 12 weeks.

Buchner et al. (*Buchner et al.*, 1997) compared cycling, walking, and an aerobic fitness class in a relatively large population of sedentary older adult population to determine the effect of these three interventions on gait speed, VO₂ max, and balance.

Table 2. Participant Characteristics

Authors	Activity Level	Population	Age (years)	n =	Male	Female
<i>Bellumori et al.</i> 2017	Sedentary-moderately active	Older	70±7.6 intervention 69.2±6.9 control	26	9	17
<i>Bogataj et al.</i> 2023	Hemodialysis patients	Hemodialysis patients	66.5±11.0	44	29	15
<i>Buchner et al.</i> 1997	Sedentary	Older	68-85	106	50	56
Harvey, Rissel, & Pijnappels 2017	Healthy	Older	75.5 ± 6.8	107	11	96
<i>Keogh et al.</i> 2018	Knee Osteoarthritis	Older	62.4 ± 8.3	17	4	13
<i>Koufaki et al.</i> 2014	Chronic Heart Failure	Adults	59.1 ± 8.6	33	30	3
<i>Kline Mangione et al.</i> 1999	Knee Osteoarthritis	Older	71.1 ± 6.9	39	13	26
<i>Macaluso et al.</i> 2003	Healthy	Older Women	69.3±2.7	38	0	38
<i>Painter et al.</i> 2000a	Hemodialysis	Adults	55.9 ± 15.5	286*	NR	NR
<i>Painter et al.</i> 2000b	Hemodialysis	Adults	57.9±14.4(low PCS) 54.2±16.6(high PCS) 52.8±16.8(con)	166	NR	NR
<i>Raso & D'Andrea Greve</i> 2012	Healthy	Older Women	65.1 ± 15.5	41	0	41
<i>Said et al.</i> 2021	Hip Fracture	Older	83 (71-89)	51	15	36
<i>Salacinski et al.</i> 2012	Knee Osteoarthritis	Adults	57.7(37-74)	37	10	27
<i>Sauvage et al.</i> 1992	Bilateral LE weakness	Older	73.38±4.04(ex); 73.83±4.74(con)	14	14	0
<i>Tatemoto et al.</i> 2019	Healthy	Young Adults	25.4±2.5	11	8	3
<i>Tollár et al.</i> 2019	Mobility Difficulty	Older	69.6±3.53	83	39	44
<i>Veldema et al.</i> 2019	Recent ICU patients	All ages	62±13(30-78)erg; 58±9 (48-79) RT; 66±14 (35-84) Con	39	23	16

* Only total participants reported

Based on the findings of this intervention, Buchner *et al.* (Buchner *et al.*, 1997) conclude that walking interventions are a more effective intervention than cycling or aerobic training due to greater improvements in balance metrics, greater improvements in leg strength, and greater improvement in VO₂max, with the walking intervention being the only intervention of the three to show significant improvements in gait speed. Based on these findings, the authors conclude that cycling exercise has very little effect on study outcomes and least useful of the three interventions (Buchner *et al.*, 1997). In this study, cycling cadence was not reported, but instead the authors defined their cycling intensity as 75% of the subject's heart rate reserve with gait speed being reported in meters per minute. Despite the walking group making greater improvements overall, the cycling group did report an improvement in gait speed with an average 3-month increase of 4 meters per minute and an additional improvement of 3 meters per minute at the 6 month follow up.

Two groups (Keogh *et al.*, 2018; Koufaki *et al.*, 2014) looked at high intensity interval training (HIIT) versus continuous aerobic cycling, with Keogh *et al.* (Keogh *et al.*, 2018) focusing on a population with knee osteoarthritis and Koufaki *et al.* (Koufaki *et al.*, 2014) focusing on patients with chronic heart failure. These two studies interestingly found dissimilar results as it related to gait speed, with Keogh *et al.* reporting a significant between-group difference in TUG scores with the HIIT group improving their TUG score significantly more than the continuous cycling group with a 1.1 second decrease in time compared to a 0.6 second increase in the continuous cycling group. The continuous cycling group did see an increased raw gait speed improvement, improving from 1.11 ± 0.17 meters per second to 1.14 ± 0.20 meters per second, with quite a large effect size of 0.14 with no change reported for the HIIT group. Keough *et al.* reported a cycling cadence of 60-80 revolutions per minute (RPMs) in the continuous cycling group and up to 110 RPMs in the HIIT group. Koufaki *et al.* reported similar changes in gait speed between both the HIIT and continuous cycling groups, with the HIIT group's gait speed improving from a baseline of 1.18 ± 0.32 m/s to 1.53 ± 0.43 m/s at 12 weeks and 1.56 ± 0.38 m/s at 24 weeks. Rather than cadence, this group determined cycling intensity for the continuous effort group as a percentage of the individual's ventilatory threshold (VT) with each participant cycling at 90% of their predetermined VT, while the HIIT group cycled for 30 second bouts at 100% peak power.

In a study published in 1999, Mangione *et al.* (Kline Mangione *et al.*, 1999) compared high and low intensity cycling in a population of older adults with knee osteoarthritis. The authors of this study defined cycling intensity as a percentage of heart rate reserve (HRR), with the high intensity group cycling at 70% HRR and the low intensity group cycling at 40% HRR. Both high and low intensity groups were found to have statistically improved their gait speed following the cycling intervention, with the high intensity group's natural gait speed improving from 1.04 ± 0.20 m/s to 1.10 ± 0.20 m/s and their forced fast walking speed improving from 1.64 ± 0.30 to 1.71 ± 0.30 , while the low intensity group's forced fast walking gait speed improved from 1.53 ± 0.35 m/s to 1.63 ± 0.36 m/s. Based on the findings of this study, the authors hypothesized that an increased reserve capacity for walking performance may be responsible for the increased gait speed.

An interventional study by Macaluso *et al.* (Macaluso *et al.*, 2003) used a mechanically braked cycle ergometer to increase cycling resistance to elicit strength adaptations in a population of older women to determine changes in gait speed based on a maximum treadmill walking speed over a 16-week intervention. The authors split participants into three groups, each cycling at different percentages of their maximal pedal resistance, with each group over the course of the 16-week trial demonstrating significantly improved maximal treadmill walking speed, with the speed group showing greater improvement than the resistance group from week 0 to week 8. The specific improvements made across time were not reported by the authors in this study. The authors also note that there was no significance in improvements between the three cycling groups.

Two studies published in the same year by Painter *et al.* (Painter *et al.*, 2000a, 2000b) looking at cycling interventions in hemodialysis patients, with both showing statistically significant improvements in gait speed with cycling interventions. In the study published in March 2000, Painter *et al.* demonstrated a significant improvement in patients' gait speed after an intervention over 8 weeks with hemodialysis patients cycling during dialysis three times per week versus those instructed to cycle at home. Over the course of this study, the cycling group improving from 66% to 69% of age expected norms, as reported by Bohannon ((Bohannon, 1997) Following this study up in September of 2000, Painter *et al.* separated patients into a low physical component scale (PCS) group

consisting of patients who scored less than a 34 on a PCS versus those scoring greater than a 34, who were grouped into a high PCS group. In this second study, the authors determined that gait speed was significantly improved in the low PCS group with this group improving from 59.2% to 64.5% of their age predicted norms, but not significantly improved in the high PCS group with the low with this group improving from 72.9% to 74.6% of their age predicted norms.

Raso and D'Andrea Greve (Raso & D'Andrea Greve, 2012) compared the effects of cycling and resistance training on ability to perform activities of daily living (ADLs) in elderly women. Specifically, they looked at the velocity at which these women were able to perform a series of tasks including time to transition from standing to sitting, standing to supine, stair climbing, and sit and tie shoes. The authors found that with both the endurance trained and resistance trained groups, participants significantly decreased the time in which it took them to climb stairs following the five-week intervention with the aerobic exercise improving their times from 8.0 ± 1.2 seconds to 7.7 ± 0.9 seconds and the resistance exercise group improving from 8.3 ± 1.8 seconds to 7.9 ± 1.6 seconds.

Said *et al.* (Said *et al.*, 2021) looked to determine the effectiveness of a cycling intervention in a non-weightbearing population following hip fractures, with the timeframe of the intervention lasting until the patient progressed to weightbearing activities. Interestingly, the authors found that while, on average, the cycling intervention group was discharged to weightbearing sooner than the control group, it was the control group with the faster gait speed at the conclusion of the study. The authors suggest that these findings are the result of a small sample size due to the nature of pilot studies, with the intervention group having a much wider range of outcomes compared to the control group. They also note two adverse events in the intervention group which included one cardiac event and one episode of infection requiring a follow-up surgery, which further affected the results.

Another interventional study targeting the knee osteoarthritis population is one by Salacinski *et al.* (Salacinski *et al.*, 2012). In this study the authors had patients perform a cycling intervention twice a week for 12 weeks to determine the effects on knee pain and functional measures. Gait velocity was measured both as a preferred gait velocity and a maximal gait velocity. The cycling group's preferred gait velocity improving from 139.3 ± 16.3 cm/s to 147.1 ± 21.5 cm/s and maximal gait velocity improving from 194.4 ± 24.7 cm/s

to 206.1 ± 27.7 cm/s, with the preferred gait velocity improving significantly compared to the control group while the improvement in the maximum velocity trial was not quite enough to be statistically significant.

An interventional cycling study targeting veterans living in a nursing home was performed by Sauvage *et al.* (Sauvage Jr. *et al.*, 1992), who looked to determine the effects of a combination of aerobic cycling and strength training on gait and balance parameters. Cycling intensity was set based on heart rate, with subjects averaging an intensity of 82% of their exercise stress-tested maximal heart rate over the course of the study. Following this 12-week study, participants in the intervention group improved their gait velocity from 44.46 ± 4.50 cm/s to 50.39 ± 5.44 cm/s, which was statistically significant, with no significant change reported in the control group.

Tollar *et al.* (Tollár *et al.*, 2019) compared the effects of an exergaming intervention against cycling five times per week for five weeks on older adults with mobility deficits. Intensity for each group was set at 80% of heart rate maximum (HRmax), with no other cycling parameters noted by the authors. Gait speed was not directly measured in this study, with the authors instead determining gait parameters using a 6-minute walk test (6MWT) and a dynamic gait index (DGI). The authors reported an improvement in the cycling group of the 6MWT of 37.3 ± 25.22 m and an improvement in DGI of 0.5 ± 2.62 over the five-week intervention, both statistically significant improvements.

Finally, Veldema *et al.* (Veldema *et al.*, 2019) compared cycle ergometer training versus resistance training over a four-week period and measure the effects on muscular strength and gait parameters in a population of recent intensive care unit (ICU) patients. Intensity for cycling was set using the Borg Scale with patients being instructed to cycle at a 13/20 level of perceived exertion with the cycle ergometer trained group improving their 10-meter walk test from a baseline of 12.6 ± 4.2 s to 8.2 ± 2.2 s to 7.3 ± 2.2 at 2 weeks and 7.30 ± 2.2 at 4 weeks. For comparison, the resistance trained group improved from a baseline of 16.5 ± 6.8 s to 10.4 ± 3.2 s at 2 weeks and 7.9 ± 2.2 at 4 weeks. Each of these improvements were statistically significant compared to the control, but it should be noted that the control group experienced spontaneous improvement as well as they recovered from their medical conditions, improving from 13.7 ± 9.2 s to 9.3 ± 2.1 s at 2 weeks and 8.1 ± 1.8 s at 4 weeks.

The strength of evidence of these studies varies anywhere from 3 to 6 on the 10-point PEDro scale. Of the studies included in this review, only one scored a grade of "poor" on the scale, with Painter *et al.* (Painter *et al.*, 2000b). study scoring a 3/10. The majority of the studies scored a "good" score with 10 of the 17 studies scoring a 6/10. These PEDro scores indicate that the current body of literature evaluating cycling interventions and gait outcomes is of moderate methodological quality, suggesting that while the reported findings are generally supportive of cycling as an intervention for improving gait speed, conclusions should be interpreted with some caution due to limitations in study design and reporting. Complete PEDro scoring for each study is presented in Table 1.

4. Discussion

The results of this literature review demonstrate a mixed response to the effects of cycling on gait parameters, with all but one study demonstrating improvement in some measurements of gait speed following a cycling intervention. The findings of this literature review highlight inconsistencies in the reporting methods for both cycling and gait parameters with the included studies measuring gait speed through inconsistent metrics. Eight of the included studies measured gait speed directly with 5 of these studies determining gait speed through the use of a 6-meter or 10-meter walk test (Bogataj *et al.*, 2023; Harvey *et al.*, 2018; Said *et al.*, 2021; Tollár *et al.*, 2019; Veldema *et al.*, 2019), two measured over 20 meters (Painter *et al.*, 2000a, 2000b), while measured gait speed over a 40-meter distance (Buchner *et al.*, 1997). Three studies measured gait speed directly through the use of a pressure mapping system to determine gait speed (Keogh *et al.*, 2018; Kline Mangione *et al.*, 1999; Salacinski *et al.*, 2012). Of the other studies included in this review, two determined walking cadence from a treadmill with one of these obtaining gait speed directly through the use of motion capture software (Sauvage Jr. *et al.*, 1992), while the other simply recorded maximum treadmill speed achieved (Macaluso *et al.*, 2003). One study in this review used a timed up and go as a surrogate for gait speed (Bellumori *et al.*, 2017), while another used a time-up-stairs as their surrogate for gait speed (Raso & D'Andrea Greve, 2012). Two studies failed to report how gait speed was obtained (Koufaki *et al.*, 2014; Tatemoto *et al.*, 2019). Exercise duration per visit also varied amongst the included studies, ranging from ten minutes to sixty minutes of cycling per session. These inconsistencies in the measuring of gait speed within the literature make it

difficult for conclusions to be drawn across a larger body of evidence on factors that may improve gait speed even in instances where similar modalities and methodologies are implemented.

The methodological quality of the included studies, as assessed using the PEDro scale, ranged from 3 to 6, indicating predominately fair to good quality evidence. These scores suggest moderate confidence in the overall finding that cycling interventions may include gait-related outcomes; however, the methodological limitations present in several studies, including limited blinding and variability in intervention reporting, indicate that conclusion should be interpreted with some caution. Complete PEDro scoring for each study is presented in Table 1.

Additionally, very few of these studies reviewed report cycling cadence when reporting their cycling intervention and prescription of cycling intensity was determined by a variety of methods. Of the seventeen studies included, only four reported cycling cadences, while three studies reported power output in watts. Seven studies determined cycling intensity by heart rate reserve (HRR) or percentage of max heart rate (%HRmax), with five studies determining intensity by using the Borg or modified Borg scale. One study determined cycling intensity based on a percentage of ventilatory threshold, while another determined it based on a percentage of maximum cycling pedal resistance. These inconsistencies in the reporting of cycling metrics make it difficult for conclusions to be drawn regarding any specific parameters of cycling that may be driving adaptation and make it difficult for these studies to be reproduced. Taken together, the available evidence suggests that cycling interventions may improve gait speed across a variety of populations; however, the limited and inconsistent reporting of cadence prevents firm conclusions regarding its independent role in driving these improvements.

There is also a question regarding the effect of intervention duration and frequency on the results seen within this review. The most common frequency of intervention was three times per week (eight studies), followed by five per week (three studies), two times per week (two studies), and four times per week (one study). Two included studies were cross-sectional rather than interventional. The duration of each intervention lasted from four to twenty-four weeks, with twelve weeks being the most common, at four studies. Said *et al.* (Said *et al.*, 2021) doesn't quite fit within this duration, as it lasted only until participants were walking and, as a result, varied per participant. These variations

in intervention frequency and duration highlight the need for further research to determine if there is an ideal recommendation for exercise prescription for cycling as a modality for improving gait speed and is an area that would benefit from further investigation.

There is also little evidence regarding what adaptations are occurring to elicit the responses seen in these studies. Through their utilization of transcranial magnetic stimulation, Tatemoto *et al.* (Tatemoto *et al.*, 2019) do suggest that neuroplasticity changes may play a role in the gait speed improvements noted through cycling interventions, while Macaluso *et al.* (Macaluso *et al.*, 2003) suggest that strength improvements, through the prescription of cycling resistance off of a repetition maximum in their study, are primarily responsible for the improvements in walking speed noted. Given the nature of these interventional studies, it may be that there are adaptations occurring both at the neuromuscular level and at the tissue level of skeletal muscle. Again, further research is needed to determine what adaptations are occurring that is responsible for the gait improvements noted in each of these studies. The findings of this review should therefore be interpreted within the context of the available literature, which is limited by variability in study design, inconsistent reporting of cycling prescription parameters, and heterogeneity in gait outcome measurements.

5. Conclusion

This literature review highlights the potential promise of cycling as an intervention for the improvement of gait speed with the body of evidence largely pointing towards it being an effective intervention for this purpose. It also highlights the need for future researchers to provide as much detail and context to the cycling interventions as possible to allow for future interventions to be more precise in their prescription while highlighting the ambiguity of the term "intensity" in cycling literature. Notably, while cycling cadence has been suggested as a potentially important variable influencing gait-related adaptations, relatively few studies within the current literature directly report cadence or isolate its effects from other exercise prescription variables. Additionally, while some researchers have hypothesized there may be a neuromuscular link between cycling and ambulation, we are only just beginning to make hypotheses regarding what underlying neuromuscular or hematological adaptations may be occurring that drive the identified changes in gait speed. The methodological quality of

the included studies, which ranged from poor to good based on PEDro scoring, suggest moderate confidence in the overall findings, while also indicating that further high-quality investigations are needed to strengthen the evidence base. Ultimately, the accessibility of cycling for a variety of populations makes it an attractive option for intervention, and through further research on specific prescription parameters (i.e. cadence, intensity, and training duration) may allow future practitioners to better improve functional outcomes for both healthy and clinical populations.

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