






Health-enhancing physical activity interventions in non-ambulatory people with severe motor impairments – a scoping review

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ABSTRACT

Purpose: Non-ambulatory people with severe motor impairments due to chronic neurological diagnoses are forced into a sedentary lifestyle. The purpose of this scoping review was to understand the type and amount of physical activity interventions performed in this population as well as their effect.

Methods: PubMed, Cochran and CINAHL Complete were systematically searched for articles describing physical activity interventions in people with a chronic, stable central nervous system lesion. The outcome measures needed to include physiological or psychological variables, measures of general health or quality of life.

Results: Of the initial 7554 articles, 34 were included after the title, abstract, and full-text screening. Only six studies were designed as randomized-controlled trials. Most interventions were supported by technologies, mainly functional electrical stimulation (cycling or rowing). The duration of the intervention ranged from four to 52 weeks. Endurance and strength training interventions (and a combination of both) were performed and over 70% of studies resulted in health improvements.

Conclusions: Non-ambulatory people with severe motor impairments may benefit from physical activity interventions. However, the number of studies and their comparability is very limited. This indicates the need for future research with standard measures to develop evidence-based, specific recommendations for physical activity in this population.

KEY MESSAGES

- Physical activity interventions can have health benefits in non-ambulatory people with severe motor impairments.
- Even simple, low-tech interventions allow for health-enhancing training.

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Introduction

Physical activity (PA) is defined as energy requiring bodily movement produced by skeletal muscle [1]. PA is significantly associated with health benefits and contributes to the prevention of non-communicable diseases (NCD) such as cardiovascular diseases, namely heart disease and stroke, as well as cancer and type 2 diabetes. In addition, PA contributes to the prevention of NCD risk factors such as hypertension, overweight and obesity. Regular PA with an appropriate intensity is also associated with improved mental health, a delay in the onset of dementia, improved

quality of life (QoL) and well-being [1]. The World Health Organization (WHO) is promoting health-enhancing physical activity (HEPA) by publishing recommendations and by setting up a global action plan [1]. However, a large proportion of the population is physically inactive, which accounts for an estimated premature mortality of 9% [2] and is considered the fourth leading risk factor for mortality [3].

Patients with chronic physical disabilities are even less physically active than the general population and, therefore, at a higher risk of serious health problems [4–6]. Stroke is associated with the lowest prevalence

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of recommended PA, only 21–31% of stroke patients perform sufficient PA. [7–9]. Physical inactivity is an important risk factor for recurrent stroke events [10]. A recent study that monitored 79 patients with stroke for two years concluded that, among others, moderate to vigorous PA is a valuable treatment for the reduction of cardiovascular risk [11]. Comparable results were found in a population-based retrospective cohort study including over 34'000 stroke survivors [8]. Reduced PA is also reported for people with chronic spinal cord injury (SCI) [12]. In a Canadian population-based study, up to 50% of participants with SCI said they did not engage in any PA at all in their leisure time. Among other factors, older age was associated with inactivity. A systematic review of children and young adults with cerebral palsy (CP) found that, regardless of their young age, they are significantly less active than peers without such conditions [13].

Habitual PA can positively influence secondary comorbidities that often accompany severe chronic conditions [14]. Guidelines recommend similar doses of PA for persons with chronic conditions as for the general population. These guidelines also emphasize the importance of PA for the secondary prevention of recurrent cardiovascular events [15–18]. Consequently, programs for the promotion of PA have been developed and investigated (for a review, see [19]). Most of these programs target patients who are able to walk; however, previous studies suggest that about 32% of survivors remain unable to walk within one year after stroke [20,21]. For non-ambulatory patients with stroke, it is even more difficult to adhere to recommended PA levels [22]. The adoption of sufficient amounts of PA depends on opportunities, e.g. specific assistive devices and the accessibility of training facilities, which provide adapted PA programs, while one's physical abilities are perceived as a barrier to a lesser extent [23]. However, regular adherence to exercise is hindered by social and emotional barriers in persons with chronic SCI [24]. Nevertheless, the potential benefit of sufficient PA is especially important for the population of non-ambulatory patients with severe motor impairments due to the forced sedentary lifestyle. With severe motor impairments, the entire body may be affected resulting in reduced or no function of the upper extremities. For these patients, a downward spiral leads to further physical deconditioning resulting in an increased risk for inactivity-associated conditions and even less PA [6]. While there are customized PA programs for persons with mild functional limitations, the promotion of HEPA for people with severe chronic functional limitations that affect both lower and upper extremities and consequently make it difficult to

perform PA individually, is sparse and hence the implementation is still in its infancy. Further, conventional measures to record the training effects may not be feasible for this specific population.

The objective of this scoping review is to provide an overview of PA interventions for non-ambulatory people with severe motor impairment due to chronic, stable central nervous system lesions (CSCNSL), a population where little is known about the options and effects of HEPA. Specifically, we looked for modes of PA provision, intensities, and outcome measures to report the effects on general health.

Methods

This scoping review was designed according to the framework defined by Arksey and O'Malley [25]: 1) identifying the research question, 2) identifying relevant studies, 3) study selection, 4) charting the data, 5) collating, summarizing, and reporting the results. Also, it followed the PRISMA Extension for Scoping Reviews (PRISMA-ScR) methodological guidelines [26,27]. The protocol of this study has been pre-registered on the Open Science Framework [28]. The process of identifying and including studies is depicted in Figure 1.

Identifying the research question

The research team consisted of exercise physiologists, movement scientists, physical therapists, and neurologists with different clinical backgrounds in neurology. In an iterative process including gathering clinical expertise and experiences, consulting scientific literature and discussions with further clinical experts and people living with impairments, the primary research question has been developed: What information is available about PA interventions in non-ambulatory adults with severe motor impairments due to neurological events? The objective was to understand the type, amount, and effect of PA participation of people with CSCNSL, who are non-ambulatory and have impaired function of the upper extremities. We defined non-ambulatory as being dependent on a wheelchair in daily life. As this information was not always included in the articles, any intervention including unsupported gait was excluded. We assumed that people with the diagnoses of CP, meningomyelocele, spina bifida, stroke, or traumatic brain injury who are non-ambulatory, also have impaired upper extremities, resulting in severe motor impairments. For SCI,

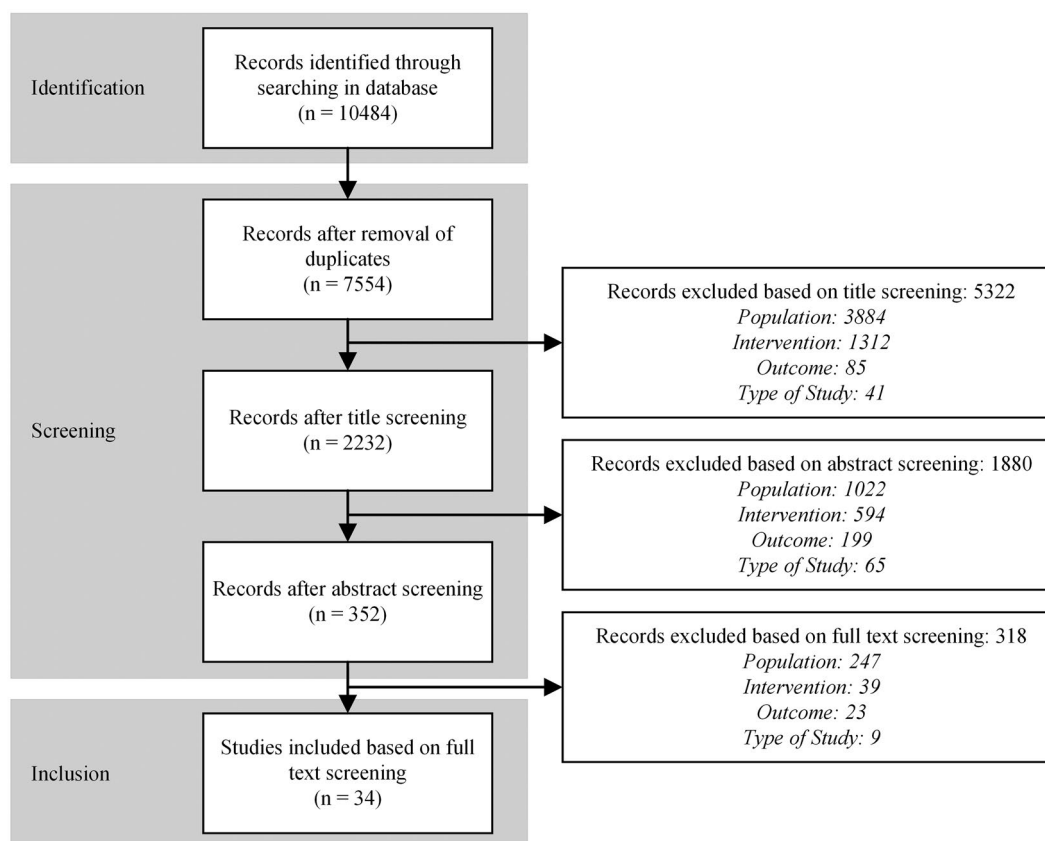


Figure 1. Flowchart of search strategy (italic fonts are the reasons for exclusion).

only cervical lesions with an American Spinal Cord Injury Association (ASIA) impairment scale of A-C [29] were included. All inclusion and exclusion criteria were defined based on PICO categories (Table 1). The selection of these variables was informed based on the reviews included in the definition of HEPA guidelines for people living with disability [30]. All types of studies except for conference proceedings, study protocols, and review articles were included.

Identifying relevant studies

The databases Cumulative Index to Nursing and Allied Health Literature (CINAHL Complete), Cochrane Database of Systematic Reviews, and PubMed were searched for articles published until 31 December 2021. Medical Subject Headings (MeSH), keywords, and other index terms were combined to construct the search strategies for each database. Six separate searches were performed, one for each diagnosis: "stroke", "brain injuries, traumatic", "quadriplegia" or "spinal cord injuries", "cerebral haemorrhage" or "spina bifida cystica" or "meningomyelocele" or "meningocele", "cerebral palsy", "chronic disease". The search for chronic

diseases was performed to ensure no articles were missed with the more specific search terms. The entire search strategy for PubMed can be found in Appendix 1. In addition, reference lists of included articles were title screened for additional relevant publications. Articles published in English or German were included. Duplicates were removed in Zotero (Corporation for Digital Scholarships, USA).

Study selection

Titles, abstracts, and full texts were consecutively screened by two reviewers for each diagnosis included in the analysis (each reviewer screened articles from their clinical expertise). A form that was tested beforehand by the study team was used to reach the inclusion/exclusion decision. All authors were involved in the screening process. Discrepancies were resolved by consensus between the two reviewers.

Articles needed to fulfil the inclusion criteria stated in Table 1. For studies with mixed groups of participants, the results for the non-ambulatory subgroup needed to be reported separately, or 70% or more of participants needed to be non-ambulatory. Excluded articles were assigned to one of four reasons for

Table 1. Inclusion and exclusion criteria for the scoping review based on PICO categories.

PICO category	Inclusion criteria	Exclusion criteria
Patients/Population	chronic diagnoses of: CP meningomyelocele spina bifida SCI (tetraplegia) ischemic and haemorrhagic stroke traumatic brain injury 18-65 years old Non-ambulatory [†] Impaired function of upper extremities*	Paralympic athletes
Interventions	Research controlled intervention related to: endurance training strength training occupational physical activity activities of daily living leisure-time physical activity	Assessment of PA without a specific intervention
Comparison	No restrictions based on comparison/control group	None
Outcome	Physiological variables: respiratory variables heart rate related variables power output blood pressure bone mineral density muscle strength body mass related variables quality of life psychological variables general health-related outcomes	Functional assessments Biomechanical assessments

[†]non-ambulatory was defined as dependent on a wheelchair in daily life.

*impaired function of upper extremities was assumed for all non-ambulatory participants with diagnoses of CP, meningomyelocele, spina bifida, stroke, tetraplegia or traumatic brain injury.

exclusion in the following order: population, intervention, outcome, and type of study (e.g. a study that did not meet the inclusion criteria for population and outcome was assigned to the population group).

Charting the data

The first author extracted the following information from each article: authors, title, year of publication, number of participants fulfilling the inclusion criteria, age, gender, diagnosis, type of study, duration of the training, target and actual number of training, number of dropouts and adverse events during the intervention, type of training, utilized devices for training, location of training, the intensity of the training, and physiological, psychological or QoL measures.

Collating, summarizing, and reporting the results

The results were summarized according to the type of PA intervention (endurance, strength, combination thereof) and the used training device (if any) as well as the duration (e.g. minutes per session but also the duration of the program, e.g. in weeks). Also, the outcome measures from the studies were grouped into overall categories (respiratory variables, PO, HR and blood pressure, body mass, BMD, muscle strength,

patient-reported outcome measures (PROMs), and qualitative measures).

Results

Articles retrieved

Of the total 7554 articles, a total of 35 fulfilled all the inclusion criteria and were included in this review. One article focused on chronic illness (CI) [31], three on CP [32–34], and 31 on SCI [35–65].

Presumably, two articles had a similar population as they were published in the same year by the same research group and the same intervention was performed; the focus of one article was subjective impressions of the participants [32] while the other article focused on the physical effects of the training [33]. However, based on the description of the participants, the population was not identical although it can be assumed that some of the participants were included in both articles. Consequently, the two articles were treated as separate studies. Another two articles were based on the same population and presented the same data [40,65]. Only the study by de Carvalho and Cliquet [40] was used for further analysis. This resulted in a total of 34 articles included in the review (Figure 1 and Table 2).

Article characteristics

A total of 417 participants were included in the 34 articles and 338 participants fulfilled the documented criteria of non-ambulatory and impaired upper extremities, although for many of these participants, it was unclear how severely affected they were. Two hundred forty-seven of the participants were male (73%) and the average age of participants in each study ranged from 23 to 64 years. In five articles, the distribution of sex was not stated [46,55,58,62,64]. The average duration since the neurological diagnosis was 12 ± 12 years. Six studies reported adverse events, which were increased shoulder pain due to muscle soreness after hand cycling that dissipated within one day [63], mild to moderate hyperreflexia during the first training of cycling with functional electrical stimulation (FES) [37], pressure sores and knee pain during body weight supported treadmill walking [47], increased pain after FES cycling [62], persistent vertigo during wheelchair dancing [34], and one study did not specify the adverse event [58].

Six articles described randomized-controlled trials [35,37,40,56,57,64], with three studies reporting drop-outs (a total of 20 participants) [35,37,56]. Twenty-three articles were a pre-post cohort study [31–34,36,38,39,42–44,46–50,52–54,58–61,63] with nine articles reporting a total of 27 dropped-out participants [33,34,39,46,47,50,58,59,63]. Four studies followed a pre-post case study design [41,45,51,55] and one study was a retrospective cohort study [62] (no drop-outs reported). There were three qualitative studies [31,32,62] and one mixed-methods approach [48], the rest of the articles followed a quantitative protocol.

The articles were published between 1980 and 2021. There has been an increase in publications in recent years. Twelve articles were published between 1980 and 1999 [37,39,41–43,46,52,53,58,60–62]. Between 2000 and 2009, ten articles were published [31–33,36,40,44,47,54,55,63], and the remaining 12 articles were published within the last eleven years [34,35,38,45,48–51,56,57,59,64].

Type and duration of physical activity interventions

There is a variety in the types of intervention among the included studies. The majority (24 studies) conducted an endurance training protocol (CP, 1 study [34], and SCI, 23 studies [35,37,38,40–47,50–52,54–56,58–63]). The second most frequently selected type of intervention was a combination of endurance and strength training, sometimes with the added

component of flexibility training (CI, 1 study [31], and SCI, 6 studies [36,39,48,49,53,57]). The remainder of the studies focused on strength training only (CP, 2 studies [32, 33], and SCI, 1 study [64]).

Investigations that conducted an endurance training protocol used either an arm crank ergometer (SCI, 9 studies, [38,41–43,50,51,56,58,63]), FES cycling (SCI, 8 studies, [37,45,52,54,55, 60–62]), combined FES cycling with an arm crank ergometer (SCI, 1 study, [35]), FES rowing (SCI, 1 study, [59]), wheelchair pushing on a treadmill (SCI, 1 study, [46]), body weight supported treadmill walking with FES (SCI, 1 study [40]) or manually assisted treadmill training (SCI, 2 studies [44,47]). When the training protocol involved both endurance and strength, two studies used FES rowing (SCI, [48,49]) or FES strength training (SCI, [36]), two studies did wheelchair rugby (SCI, [39,53]) and one study each used circuit training (SCI, [57]), or no special equipment (CI [31]). In the CP group, strength training was performed using devices available in a community gymnasium [32,33], while endurance training was done by performing wheelchair dancing and therefore not needing additional equipment [34]. One study did a specific strength training program for respiratory muscles using designated equipment. They performed training of the respiratory muscles in a randomized controlled trial in participants with SCI. Participants performed normocapnic hyperpnoea training, which included hyperventilating through partial re-breathing of ventilated air [64].

The duration of the entire training program as well as the individual sessions varied largely. The duration of the training program per participant ranged from four to 52 weeks, one study included participants who had been training outside of study procedures for up to 2.5 years [62]. The frequency of training ranged from once per week until 5 times per week with most studies performing 3 training bouts per week. The attendance ranged between 57% and 100% of all training sessions [31–37,39,41,43–47,49,50,53,55,57–60]. However, 12 studies did not report this information [38,40,42,48,51,52,54,56,61–64]. The duration of an individual training session ranged from less than 10 min [34] to up to 90–120 min [32,33,39,53].

For the studies that performed specific strength training, the training intensity was mostly determined by the one repetition maximum (1RM). Two studies had it set at 60–80% for two sets of 8–10 repetitions [32, 33], while one study used a similar approach but at 50–60% of 1RM [57].

Variables that were used to set the intensity for endurance training were: Borg CR10 scale

Table 2. Characteristics of included articles.

Reference	Study design	Intervention		Participants		Outcomes related to general health	Change in outcomes related to general health
		Type of training, form of training, target duration per participant, target training frequency	Strength, equipment from community gymnasium, 10 weeks, 2x/week Endurance, FES cycling and arm ergometer, 16 weeks, 2x/week	Number of participants fulfilling inclusion criteria (total number of participants), mean age [†] Number of male subjects [†] , diagnosis	Qualitative outcomes		
Allen et al. 2004 [32]	Pre-post cohort	Endurance, FES cycling and arm ergometer, 16 weeks, 2x/week	7 (10), 44 years 3 ♀, CP		Perceived strength: increased	<i>Italic: based on statistical analysis</i>	
Bakkum et al. 2015 [35]	Randomized controlled trial	Endurance, FES cycling and arm ergometer, 16 weeks, 2x/week	8 (20), 49 years 8 ♀, SCI		VO ₂ max: no change peakPO: no change restingHR: reduced submaxHR: no change maxHR: no change PASIPD: increased BMD: increased strength: increased BMD: increased		
Bélangier et al. 2000 [36]	Pre-post cohort	Endurance & strength, FES, 24 weeks, 5x/week	14 (14), 32 years 11 ♀, SCI		BMD Strength BMD		
Bloomfield et al. 1996 [37]	Randomized controlled trial	Endurance, FES cycling, 9 months, 3x/week	11 (17), 32 years 5 ♀, SCI		Power output Heart rate Oxygen consumption Power output Heart rate Strength		
Brizuela et al. 2020 [38]	Pre-post cohort	Endurance, arm ergometer, 8 weeks, 2x/week	11 (11), 37 years 8 ♀, SCI		Power output Heart rate Oxygen consumption Power output Heart rate Strength		
Dallmeijer et al. 1997 [39]	Pre-post cohort	Endurance & strength, wheelchair rugby, 6 months, 1x/week	24 (24), 32 years 8 ♀, SCI		Oxygen consumption		
de Carvalho & Cliquet 2005 [40]	Randomized controlled trial	Endurance, body weight supported walking with FES, 6 months, 2x/week	21 (21), 32 years 21 ♀, SCI		Body mass/composition Oxygen consumption Power output Heart rate		
Di Carlo 1982 [41]	Pre-post case study	Endurance, arm ergometer, 8 weeks, 3x/week	1 (1), 24 years 1 ♀, SCI		Body mass/composition Oxygen consumption Power output Heart rate		
Di Carlo 1983 [43]	Pre-post cohort	Endurance, arm ergometer, 5 weeks, 3x/week	4 (4), 24 years 4 ♀, SCI		Body mass: no change VO ₂ max: increased peakPO: increased VO ₂ max: increased peakPO: increased submaxHR: decreased blood pressure: no change		
Di Carlo 1988 [42]	Pre-post cohort	Endurance, arm ergometer, 8 weeks, 3x/week	8 (8), 24 years 8 ♀, SCI		Body mass/composition BMD PROM (QoL)		
Ditor et al. 2005 [44]	Pre-post cohort	Endurance, body weight supported walking with manual assistance, 6 months, 3x/week	8 (8), 28 years 6 ♀, SCI		Body mass/composition BMD PROM (QoL)		
Dolbow et al. 2012 [45]	Pre-post case study	Endurance, FES cycling, 9 weeks, 3x/week	1 (1), 64 years 1 ♀, SCI		Body mass/composition BMD PROM (QoL)		
Gass et al. 1980 [46]	Pre-post cohort	Endurance, wheelchair ergometer, 7 weeks, 5x/week	7 (7), 34 years not specified, SCI		Body mass/composition Oxygen consumption Heart rate		
Giangregorio et al. 2006 [47]	Pre-post cohort	Endurance, body weight supported walking with manual assistance, 1 year, 3x/week	13 (13), 29 years 11 ♀, SCI		Body mass/composition BMD qualitative outcomes		

(Continued)

Table 2. Continued.

Reference	Intervention		Participants		Outcomes related to general health	Change in outcomes related to general health
	Study design	Type of training, form of training, target duration per participant, target training frequency	Number of participants fulfilling inclusion criteria (total number of participants), mean age ^a	Number of male subjects, diagnosis		
Gibbons et al. 2014 [48]	Pre-post cohort	Endurance & strength, FES rowing and FES leg conditioning, 1 year, 7x/week	8 (8), 31 years 4 ♀, SCI		Power output Qualitative outcomes	peakPO: increased averagePO: increased perceived physical well-being: increased <i>Italic: based on statistical analysis</i>
Gibbons et al. 2016 [49]	Pre-post cohort	Endurance & strength, FES rowing and FES leg conditioning, 8 weeks, 7x/week	3 (5), 31 years 1 ♀, SCI		Oxygen consumption Power output Heart rate	<i>VO₂max: increased</i> <i>peakPO: increased</i> <i>averagePO: increased</i> <i>maxHR: increased</i> perceived psychological well-being: increased
Graham et al. 2008 [31]	Pre-post cohort	Endurance, strength and flexibility, unweighted exercises for endurance, strength, and flexibility, 24 weeks, 2x/week	11 (11), 58 years 8 ♀, variable chronic diseases*		Qualitative outcomes	
Han et al. 2016 [50]	Pre-post cohort	Endurance, arm ergometer, 12 weeks, 3x/week	6 (11), 40 years [#] 11 ♀ [#] , SCI		Body mass/composition Oxygen consumption Heart rate Blood pressure	<i>VO₂max: no change</i> <i>restingHR: no change</i> <i>maxHR: no change</i> <i>blood pressure: no change</i> <i>Body mass: no change</i> <i>VO₂max: increased</i> <i>peakPO: increased</i> <i>averagePO: increased</i> <i>body fat: decreased</i> <i>VO₂max: increased</i> <i>body fat: decreased</i> <i>lean body mass: increased</i> <i>BMD: no change</i> <i>VO₂max: no change</i> <i>peakPO: no change</i> <i>maxHR: no change</i> <i>VO₂max: increased</i> <i>peakPO: increased</i> <i>maxHR: increased</i> <i>BMD: increased</i> <i>VO₂max: increased</i> <i>waist circumference: decreased</i> <i>BMI: decreased</i> <i>strength: increased</i> <i>VO₂max: increased</i> <i>body mass: increased</i> <i>strength: increased</i>
Hamish et al. 2017 [51]	Pre-post case study	Endurance, arm ergometer, 14 weeks, 2-3x/week	1 (1), 42 years 1 ♀, SCI		Body mass/composition Oxygen consumption Power output	
Hjeltnes et al. 1997 [52]	Pre-post cohort	Endurance, FES cycling, 8 weeks, 7x/week	5 (5), 35 years 5 ♀, SCI		Body mass/composition BMD Oxygen consumption	
Hopman et al. 1996 [53]	Pre-post cohort	Endurance & strength, wheelchair rugby, 6 months, 1x/week	21 (21), 32 years 14 ♀, SCI		Oxygen consumption Power output Heart rate	
Janssen & Pringle 2008 [54]	Pre-post cohort	Endurance, FES cycling, 6 weeks, 2-3x/week	6 (6), 36 years 6 ♀, SCI		Oxygen consumption Power output Heart rate	
Kakebeeke et al. 2008 [55]	Pre-post case study	Endurance, FES cycling, 1 year, 5x/week	1 (1), 31 years 1 ♀, SCI		BMD Oxygen consumption Power output Heart rate	
Kim et al. 2015 [56]	Randomized controlled trial	Endurance, arm ergometer, 6 weeks, 3x/week	13 (15), 33 years 8 ♀, SCI		Body mass/composition Oxygen consumption Strength	
Kressler et al. 2014 [57]	Randomized controlled trial	Endurance & strength, circuit resistance training, 26 weeks, 3x/week	11 (11) 42 years 9 ♀, SCI		Body mass/composition Oxygen consumption Strength	

(Continued)

Table 2. Continued.

Reference	Intervention		Participants		Outcomes related to general health	Change in outcomes related to general health
	Study design	Type of training, form of training, target duration per participant, target training frequency	Number of participants fulfilling inclusion criteria (total number of participants), mean age [†]	Number of male subjects, diagnosis		
McClean & Skinner 1995 [58]	Pre-post cohort	Endurance, arm ergometer, 10 weeks, 3x/week	14 (14), 34 years not specified, SCI		Body mass/composition Oxygen consumption Power output	<i>VO₂max: increased</i> <i>peakPO: increased</i> <i>restingHR: increased</i> <i>body mass: no change</i> <i>VO₂max: increased</i> <i>maxHR: no change</i> <i>VO₂max: increased</i> <i>peakPO: increased</i> <i>BMD: increased</i> <i>VO₂max: increased</i> <i>restingHR: no change</i> <i>maxHR: increased</i> <i>blood pressure: decreased</i> <i>perceived physical and psychological well-being: increased</i> <i>strength: increased</i>
Mercier et al. 2021 [59]	Pre-post cohort	Endurance, FES rowing, 6 months, 3x/week	15 (27), 30 years [#] 26 [♀] , SCI		Oxygen consumption heart rate BMD	<i>VO₂max: increased</i> <i>maxHR: no change</i> <i>VO₂max: increased</i> <i>peakPO: increased</i> <i>BMD: increased</i>
Mohr et al. 1997 [60]	Pre-post cohort	Endurance, FES cycling, 1 year, 3x/week	6 (10), 35 years [#] 8 [♀] , SCI		Oxygen consumption Power output Heart rate Blood pressure	<i>VO₂max: increased</i> <i>restingHR: no change</i> <i>maxHR: increased</i> <i>blood pressure: decreased</i> <i>perceived physical and psychological well-being: increased</i> <i>strength: increased</i>
Pollack et al. 1989 [61]	Pre-post cohort	Endurance, FES cycling, 13–28 weeks, 3x/week	7 (11), 27 years 4 [♀] , SCI		Qualitative outcomes	<i>VO₂max: increased</i> <i>restingHR: no change</i> <i>maxHR: increased</i> <i>blood pressure: decreased</i> <i>perceived physical and psychological well-being: increased</i> <i>strength: increased</i>
Sipski et al. 1989 [62]	Retrospective cohort	Endurance, FES cycling, 1.5 months to 2.5 years, frequency not stated	34 (52), 40 years [#] 37 [♀] , SCI		Qualitative outcomes	<i>VO₂max: increased</i> <i>restingHR: no change</i> <i>maxHR: increased</i> <i>blood pressure: decreased</i> <i>perceived physical and psychological well-being: increased</i> <i>strength: increased</i>
Taylor et al. 2004 [33]	Pre-post cohort	Strength, resistance strength training with various gym equipment, 10 weeks, x/week	7 (10), 27 years [#] 7 [♀] , CP		Strength	<i>VO₂max: increased</i> <i>restingHR: no change</i> <i>maxHR: increased</i> <i>blood pressure: decreased</i> <i>perceived physical and psychological well-being: increased</i> <i>strength: increased</i>
Terada et al. 2017 [34]	Pre-post cohort	Endurance, wheelchair dancing supported by able-bodied person, 1 year, 2–3x/week	6 (6), 40 years 2 [♀] , CP		Oxygen pulse	<i>VO₂max: increased</i> <i>peakPO: increased</i> <i>submaxHR: no change</i> <i>strength: increased</i> <i>PHQ-9: decreased</i> <i>SGRQ: decreased</i>
Valent et al. 2009 [63]	Pre-post cohort	Endurance, arm ergometer, 8–12 weeks, 2–3x/week	15 (15), 29 years unclear, SCI		Oxygen consumption Power output Heart rate Strength PROM (PHQ-9 & SGRQ)	<i>VO₂max: increased</i> <i>peakPO: increased</i> <i>submaxHR: no change</i> <i>strength: increased</i> <i>PHQ-9: decreased</i> <i>SGRQ: decreased</i>
Xi et al. 2019 [64]	Randomized controlled trial	Strength, respiratory muscle training, 4 weeks, 5x/week	10 (18), 53 years not specified, SCI		Strength	<i>VO₂max: increased</i> <i>peakPO: increased</i> <i>submaxHR: no change</i> <i>strength: increased</i> <i>PHQ-9: decreased</i> <i>SGRQ: decreased</i>

BMD: bone mineral density; BMI: body mass index; CP: cerebral palsy; FES: functional electrical stimulation; HR: heart rate; O₂P: oxygen pulse; PASIPD: physical activity scale for individuals with physical disabilities; PHQ-9: Patient Health Questionnaire-9; PO: power output; PROM: patient-reported outcome measures; QoL: quality of life; SCI: spinal cord injury; SGRQ: St George's Respiratory Questionnaire; TBI: traumatic brain injury; VO₂max: maximal oxygen consumption.

[†]values of participants fulfilling the inclusion criteria of this review.

[#]values of participants fulfilling the inclusion could not be differentiated from the entire study population.

*5 with stroke, 6 with either SCI, TBI, cancer, chronic pain, arthritis, or diabetes.

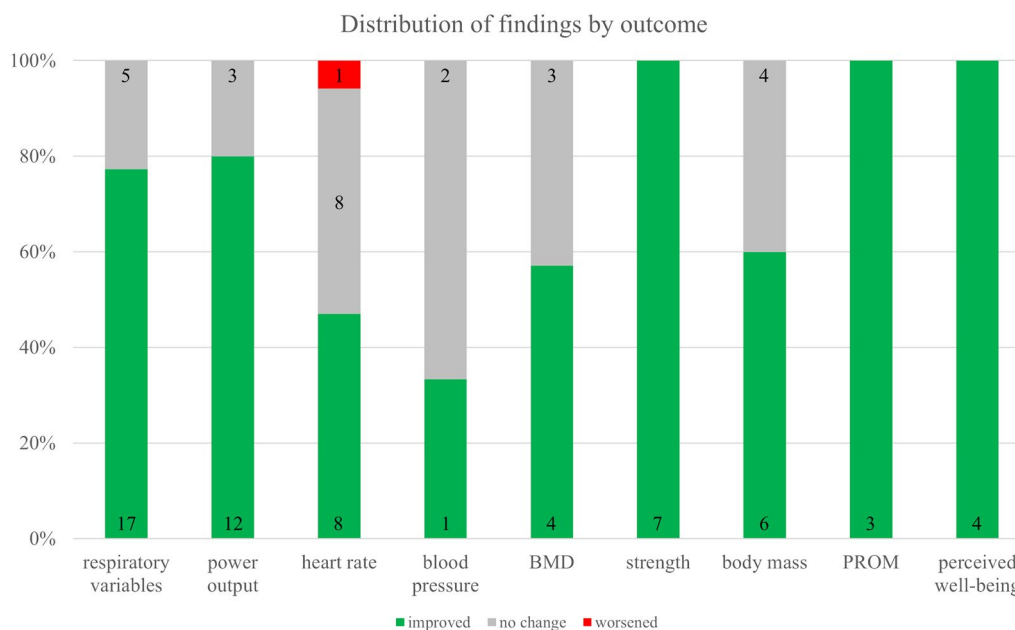


Figure 2. Percentage of articles that found improved, not changed, or worsened outcomes after a PA intervention grouped according to outcome category. Data labels indicate the absolute number of articles. BMD: bone mineral density, PROM: patient-reported outcome measures.

[35,38,49,56,63,66], variables related to the HR (e.g. HR reserve) [35,42,43,57,59,63], the anaerobic threshold [50], certain percentages of VO_2 max [49] or peak PO [51,58], individual pain tolerance, fatigue, or the ability to withstand a specific training time [36,37,40,44,46,47,52,55,60,61].

Effects of physical activity interventions

Of the 34 studies, 29 concluded that their exercise protocol was beneficial for the health of the participants [31–34, 36–38, 41–49, 51, 52, 54–64], the others were inconclusive or no benefit was observed [35, 39, 40, 50, 53]. The number and percentage of studies that found improvements for each outcome category are displayed in Figure 2.

Respiratory variables (Oxygen uptake & Oxygen pulse)

The studies that looked at quantitative physiological outcomes measured a large variety of variables. The variable that was measured most often was maximal oxygen consumption (VO_2 max). Sixteen studies found an increased VO_2 max after the training intervention [41–43,46,49,51,52,54–61,63], while five studies did not find a change [35,39,40,50,53]. Not all studies that reported an increase had a sufficient sample size to calculate statistical effects. Ten of the studies performed the VO_2 max test with an arm crank ergometer

[41–43,50,51,53,56–58,63]. Five studies used an FES bicycle [52,54,55,60,61], three a wheelchair ergometer [35,39,46], two FES rowing [49, 59] and one study included FES-supported treadmill walking [40].

One study analysed the change in oxygen pulse (O_2P), a relative measure of stroke volume, during a wheelchair dance intervention and found increased O_2P after three months [34].

Power output

Another more widely used variable was maximal or average PO. Nine studies reported an increase in peak PO [38,41–43,54,55,58,60,63] although not all studies were able to calculate significant changes due to limited sample size. Three studies did not find a change in peak PO [35,39,53]. The three studies that measured both maximal and average PO found similar results, with an increase in both variables [48,49,51]. The arm crank ergometer was used in nine studies [38,41–43,49,51,53,58,63], three studies used an FES bicycle [54,55,60], one study did FES rowing [48] and two studies used a wheelchair ergometer [35,39].

Heart rate & blood pressure

The HR at rest, during submaximal, or maximal effort were utilised by some studies as measures of the effect of the exercise. While two studies found a reduction in resting HR [35,44], two studies found no change [50,61]

and one found an increased resting HR [58]. The HR during submaximal effort was found to be decreased at the same workload for two studies [41,42] while four studies found no change [35,38,39,63]. Similarly, four studies found an increased maximal HR after training [49,54,55,61] while five studies found no change [35,46,50,53,59]. Three studies measured blood pressure at rest or during maximal workload [44,50,61] but only one study found a moderately but significantly decreased diastolic blood pressure after training [61].

Body mass/composition

Some studies focused on body mass and derivatives thereof. Three studies found a decrease in fat mass or percent body fat [45,51,52], three an increase in lean body mass [45,47,52], one a decrease in waist circumference [56], or a decreased body mass index [56]. One study found an increase in body mass, however, they were unable to determine if the increase was in lean or fat body mass [57]. Four studies did not find changes in variables related to body mass or composition [41,46,50,58]. All the studies that examined changes in body mass or composition followed an endurance training protocol, one in combination with strength training [57].

Bone mineral density

A variable examined in seven studies was the BMD. Four studies found increased BMD [36,37,55,60] at least at some measurement sites, while three studies did not find changes in BMD [45,47,52]. The three studies with no changes performed FES cycling between eight [52] and 24 weeks [45] or body weight-supported treadmill walking with manual assistance for one year [47]. The studies with changes in BMD did FES strength training or FES cycling for a duration of 24 weeks [36,37] to one year [55,60].

Muscle strength

Looking at muscle strength, the studies found increases in some of the evaluated muscle groups for all interventions: FES-enabled strength training, wheelchair rugby, hand cycling, and circuit training [33,36,39,56,57,63].

Patient reported outcome measures

Training with an arm crank ergometer alone or combined with FES-cycling results in an increase in the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) which is a self-reported measure of PA in daily life [35]. Looking at QoL, Dolbow et al.

found improvements in the psychological domain of the WHOQOL-Bref in their case study conducting FES cycling [45]. The study with strength training of the respiratory muscles found significant improvements in the presence and severity of depressive symptoms (based on Patient Health Questionnaire-9), impact on overall health, daily life and perceived well-being (based on St. George's Respiratory Questionnaire) [64].

Qualitative measures

Based on qualitative analyses, exercise in a group setting without specific equipment has been described as a means to manage mood and pain, invest in oneself, preserve and enhance the self-image, and allow connecting with the body [31,62]. Further, a perceived improvement in the ability to perform activities of daily living (after FES-rowing [48] and gymnasium-based strength training [32]) has been reported. Anecdotal reports on decreased limb oedema, reduced spasticity, a feeling of warm feet and discontinued use of stockings were reported by Giangregorio et al. [47]. Also, Allen et al. who conducted a gymnasium-based strength training, reported a perceived increase in strength, that the group setting increased the enjoyment and social interaction but that short-term muscle soreness and the realization that the physical improvements are limited may negatively influence participants [32].

Discussion

The aim of this scoping review, including 34 articles, was to gain an overview of the type of PA interventions possible and its effect on non-ambulatory people with severe motor impairments due to CSCNSL. Based on this information, future studies can be designed addressing gaps in the literature. The literature was charted according to the type of intervention and the measured outcomes.

With only six articles following a randomized-controlled trial design, the pre-post cohort and case studies often including only a very small sample size, which results in limited power, and the fact, that there is no substantial increase in research over the last few years indicate the infancy of this research area. This is also underlined by the fact that there are recommendations for PA by the WHO for a large variety of populations; however, for people with severe motor limitations, there exist no specific recommendations so far [1].

Participants

In this scoping review, studies with participants with a variety of diagnoses were included. However, the

majority of studies focused solely on people with SCI. A potential reason for this being that SCI often occur at a younger age and lead to early aging [67], resulting in a need for secondary prevention. Also, especially complete SCI results in clearly defined functional impairments which facilitates research. Only one study included people with variable diagnoses [31]. While some physiological responses to PA may differ depending on the diagnosis e.g. pertaining to autonomic nervous system function like cardiorespiratory responses or thermoregulation [68,69], it is speculated that other health-enhancing effects of PA are comparable between diagnoses. Interestingly, the one study including multiple diagnoses did measure the effect of PA on perceived psychological well-being and found an improvement over all diagnoses [31].

The time since diagnosis, age, sex, and functional abilities (ambulation status, function of upper extremities) was not always stated and often results from ambulatory and non-ambulatory participants were not differentiated, which complicated the inclusion and comparison of the studies.

Type and duration of physical activity interventions

Most studies reported on an endurance training protocol, followed by a combined endurance and strength protocol, while three studies performed only strength training. This corresponds to the WHO guidelines on PA and sedentary behaviour, where aerobic PA is recommended primarily and strength training is an additional recommended activity [1]. The duration of individual training sessions were very variable, even within studies. Eighteen studies achieved at least the WHO-recommended weekly duration of vigorous PA for adults living with a disability (75-150 min) [1]. Only five of the studies reached the necessary duration for moderate-intensity aerobic PA (150-300 min). Whether in the studies moderate or vigorous-intensity PA was performed cannot be differentiated. Four studies did not reach the minimum PA duration, while for the remaining studies, this could not be determined precisely. The studies that did not reach the minimum PA duration found only small effects, which could indicate that also the population of CSCNSL needs to reach a minimum duration of PA [31,34,35,40]. The WHO recommendations also include muscle-strengthening activities and additional functional balance and strength training. With only very few studies including all recommended components, it can be concluded that generally, the interventions did not achieve the

recommended amount of PA combining aerobic PA and strength training.

Although the duration of the interventions was highly variable, there were 13 studies with a duration of 6 months or longer. This, in combination with the reported attendance rate, shows that the necessary adherence even over a longer duration may be achieved in this population.

Interventions ranged from very simple (unweighted exercises or wheelchair dancing) to highly technological (FES cycling, FES rowing, or body weight-supported treadmill walking). Also, simple methods to guide the training intensity (Borg CR10 scale, pain) can be used. If, however, more complex variables want to be used (e.g. VO_2 max or PO) to guide the training or quantify the effect of the training, more advanced technologies are necessary, although, with arm crank ergometers, an access device is used often. Exoskeletons for rehabilitation were, however, not used in any of the studies, although their efficacy has been shown in related but different populations [70–72]. Most of the chosen interventions either required active muscle contractions or induced muscle contractions. The one exception is wheelchair dancing, where most movements were done passively by a dancing partner [34]. With this study showing improvement in the O_2P , it can be assumed that even interventions based on passive movements (due to human manipulation or robotics) may induce health-beneficial physiological changes and are therefore worth examining.

Effects of physical activity interventions

Many of the studies showed the health-beneficial effects of the interventions with a small number and non-serious adverse events. This indicates that this population can train safely with the chosen interventions. For the physiological variables, respiratory measures, PO, as well as strength, showed improvements in most of the studies that assessed these variables. For HR-related variables and blood pressure, the number of studies that showed an improvement was about equal to the number of studies with no change. This may be related to the fact that most studies trained people with SCI and the regulation of the HR as well as blood pressure is affected by the injury to the spinal cord and may, therefore, not react to PA as can be expected in other populations [73,74]. About half of the studies found an improvement in BMD. Two of the three studies that did not find a change in BMD had a duration of the intervention of 8 or 9 weeks, which is rather short for the BMD to change [75]. Further, some studies analysed BMD of the whole body or at the spine, which may not be the

location where a change of BMD could be expected, e.g. the lower extremities. The studies that did not find a change in body mass did not differentiate between fat mass and lean body mass, which may be an explanation for the lack of effect.

The PROMs as well as the perceived well-being (physical and psychological) improved in all studies that assessed these variables. There was a great variety of questionnaires for PROMs and perceived well-being was assessed qualitatively without standardized assessments. This impedes the comparison between studies. The lack of these variables in most studies (only seven studies included PROMs and qualitative assessment of well-being) indicates the neglect of such effects of PA during studies. This is comparable to the studies used to develop the WHO guidelines for PA for adults living with disabilities. Of the 20 studies addressing people with SCI or stroke, only two examined the effects of PA on the QoL [30]. Future studies examining HEPA need to report not only physiological effects but also the psychological responses of the participants to provide a holistic analysis of the effects of PA.

There were only two studies that did not find a health-beneficial effect in any of the measured variables after the intervention. Consequently, this indicates that the population of people with severe motor impairments due to CSCNSL may in fact have a health-related benefit of PA. We are not able to recommend a certain intensity or frequency of the training, more research focusing on these aspects for this specific population is needed to develop evidence-based training recommendations.

Limitations and strengths of review

In this review, multiple CSCNSL diagnoses were grouped together, an approach, which is not typically done. While there are functional characteristics that are comparable, there are also diagnosis-specific characteristics that may affect the reaction to PA. And while looking at each diagnosis individually may facilitate the conduct and interpretation of studies, including multiple diagnoses can increase the generalizability of results. However, the included diagnoses were not represented equally, the vast majority studied SCI exclusively which limits the generalizability of the results. The predicted rising incidence of strokes and decrease in mortality due to stroke [76] shows that there is an urgency in obtaining more information specifically for this population.

Only studies that performed a PA intervention were included in this scoping review. Other forms of PA, for

example during physical therapy or during activities of daily living were not considered. The goal of the scoping review was to gain an overview of PA interventions in this population which led to the exclusion of other forms of PA. To have complete knowledge of HEPA, activities it would be necessary to include information about activities of daily life and other PA in future research. However, determining the level of activity in people with CSCNSL may be challenging.

In this review, the focus was on a neglected population that contributes to the equality of this group in research. The methodology followed a systematic approach, and the protocol was pre-registered to enhance the transparency of the study process.

Future directions

This scoping review identified different gaps in the literature that should be addressed in future research. The devices utilized for training were limited to arm cranking, FES, body weight-supported walking, wheelchairs, or regular gym equipment. It can be speculated, that rehabilitation robotics may also be utilized for HEPA training in people with severe motor impairments. An exoskeleton has previously been successfully used for cardiovascular fitness training early after stroke [70]. It remains to be determined if such devices are effective training devices for people with severe, chronic stable central nervous system lesions. Should such training be effective, technological advancements would be necessary to allow training outside of laboratory or clinical settings, for example in a community gym or even at home which would decrease a major barrier to physical activity [23].

Further, the dose-response relationship between physical activity and different variables related to health needs to be explored in more detail. Additionally, no information about the long-term benefits of a training intervention in people with severe impairments is currently available. Together with raising awareness of exercise as medicine [77], knowledge of the long-term effects of training in this population would be crucial to develop health service models facilitating access to training (e.g. through a financial contribution by insurance).

Conclusion

This scoping review identified evidence that non-ambulatory people with severe motor impairments due to CSCNSL may have health benefits from PA

interventions, that such interventions can be done safely, and that the necessary adherence is possible. While a variety of interventions were reported, the use of rehabilitation robotics to facilitate training needs to be examined in future research. The range of interventions from very simple to highly technological also shows that PA interventions could be implemented in any setting, enabling healthcare professionals to also consider simple settings to allow their patients to be physically active, even if only passively. It appears, however, necessary, that the WHO-recommended amount of PA is reached, to gain a health benefit from the intervention.

With most interventions targeting endurance training, to comply with the WHO recommendations, a combined approach with endurance and strength training is necessary. To ensure comparability between studies, standard measures for reporting of the training intensity (according to WHO guidelines) and outcomes must be utilized. Also, both the physiological and psychological effects of PA need to be examined jointly to gain knowledge of the effect on health in general.

Author contributions

E.S.G, C.P, R.L., J.C.M, M.W. were involved in the conception and design, analysis and interpretation of the data, revising the article and final approval of the version to be published. E.S.G. and M.W. were involved in drafting the paper. All authors agree to be accountable for all aspects of the work.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, E.S.G., upon reasonable request.

References

- [1] World Health Organization. WHO guidelines on physical activity and sedentary behaviour. Geneva: World Health Organization; 2020. Available from <https://apps.who.int/iris/handle/10665/336656>
- [2] Lee I-M, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012; 380(9838):1–16.
- [3] World Health Organization. Global recommendations on physical activity for health. 2010. Available from <https://www.who.int/publications-detail-redirect/9789241599979>.
- [4] de Hollander EL, Proper KI. Physical activity levels of adults with various physical disabilities. *Prev Med Rep*. 2018;10:370–376.
- [5] Rimmer JH, Marques AC. Physical activity for people with disabilities. *Lancet*. 2012; 380(9838):193–195.
- [6] Hart DA. Learning from human responses to deconditioning environments: improved understanding of the “use it or lose it” principle. *Front Sports Act Living*. 2021;3:685845.
- [7] Aguiar LT, Martins JC, Nadeau S, et al. Efficacy of interventions to improve physical activity levels in individuals with stroke: a systematic review protocol. *BMJ Open*. 2017; 7(1):e012479. [Internet].
- [8] Kang S-M, Kim S-H, Han K-D, et al. Physical activity after ischemic stroke and its association with adverse outcomes: a nationwide population-based cohort study. *Top Stroke Rehabil*. 2021; 28(3):170–180.
- [9] Brawner CA, Churilla JR, Keteyian SJ. Prevalence of physical activity is lower among individuals with chronic disease. *Med Sci Sports Exerc*. 2016; 48(6):1062–1067.
- [10] Shani SD, Varma RP, Sarma PS, et al. Life style and behavioural factors are associated with stroke recurrence among survivors of first episode of stroke: a case control study. *J Stroke Cerebrovasc Dis*. 2021; 30(4):105606.
- [11] Fini NA, Bernhardt J, Churilov L, et al. A 2-year longitudinal study of physical activity and cardiovascular risk in survivors of stroke. *Phys Ther*. 2021;101:pzaa205.
- [12] Nightingale TE, Metcalfe RS, Vollaard NB, et al. Exercise guidelines to promote cardiometabolic health in spinal cord injured humans: time to raise the intensity? *Arch Phys Med Rehabil*. 2017;98(8):1693–1704.
- [13] Carlon SL, Taylor NF, Dodd KJ, et al. Differences in habitual physical activity levels of young people with cerebral palsy and their typically developing peers: a systematic review. *Disabil Rehabil*. 2013;35(8):647–655.
- [14] Durstine JL, Painter P, Franklin BA, et al. Physical activity for the chronically ill and disabled. *Sports Med*. 2000; 30(3):207–219.
- [15] Billinger SA, Arena R, Bernhardt J, et al. Physical activity and exercise recommendations for stroke survivors: a statement for healthcare professionals from the American heart association/American stroke association. *Stroke*. 2014; 45(8):2532–2553.
- [16] Geidl W, Abu-Omar K, Weege M, et al. German recommendations for physical activity and physical activity promotion in adults with noncommunicable diseases. *Int J Behav Nutr Phys Activ*. 2020;17:1–13. 5

- [17] Carty C, van der Ploeg HP, Biddle SJH, et al. The first global physical activity and sedentary behavior guidelines for people living with disability. *J Phys Act Health*. 2021;18(1):86–93. 1
- [18] Pfeifer K, Geidl W. Bewegungsempfehlungen für erwachsene mit einer chronischen Erkrankung – methodisches vorgehen, datenbasis und begründung [physical activity recommendations for adults with a chronic disease – methodological approach, data basis and rationale]. *Gesundheitswesen*. 2017;79(S 01):S29–S35.
- [19] Saunders DH, Sanderson M, Hayes S, et al. Physical fitness training for stroke patients. *Cochrane Database Syst Rev*. 2020;3:CD003316.
- [20] Kelly-Hayes M, Beiser A, Kase CS, et al. The influence of gender and age on disability following ischemic stroke: the framingham study. *J Stroke Cerebrovasc Dis*. 2003;12(3):119–126. 1
- [21] Luengo-Fernandez R, Paul NL, Gray AM, et al. Population-Based study of disability and institutionalization after transient ischemic attack and Stroke. 2013; 44(10):2854–2861.
- [22] Lloyd M, Skelton DA, Mead GE, et al. Physical fitness interventions for nonambulatory stroke survivors: a mixed-methods systematic review and meta-analysis. *Brain Behav*. 2018;8(7):e01000.
- [23] Reicherzer L, Wirz M, Wieber F, et al. Facilitators and barriers to health-enhancing physical activity in individuals with severe functional limitations after stroke: a qualitative study. *Front Psychol*. 2022;13: 982302.
- [24] Baehr LA, Kaimal G, Hiremath SV, et al. Staying active after rehab: physical activity perspectives with a spinal cord injury beyond functional gains. *PLoS One*. 2022;17(3):e0265807.
- [25] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8(1):19–32. 1
- [26] Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169(7):467–473.
- [27] Lockwood C, Tricco AC. Preparing scoping reviews for publication using methodological guides and reporting standards. *Nurs Health Sci*. 2020;22(1):1–4.
- [28] Graf E, Wirz M, Perret C, et al. Health enhancing physical activity in people with stable, chronic central nervous system lesion - HEPA+. 2020. December 18 [cited 2022 24]. Available from: <https://osf.io/34acz>.
- [29] Roberts TT, Leonard GR, Cepela DJ. Classifications in brief: American spinal injury association (ASIA) impairment scale. *Clin Orthop Relat Res*. 2017;475(5):1499–1504.
- [30] World Health Organization. WHO guidelines on physical activity and sedentary behaviour: web annex: evidence profiles. Geneva: World Health Organization; 2020. Available from <https://apps.who.int/iris/handle/10665/336657>
- [31] Graham R, Kremer J, Wheeler G. Physical exercise and psychological well-being among people with chronic illness and disability: a grounded approach. *J Health Psychol*. 2008; 13(4):447–458.
- [32] Allen J, Dodd KJ, Taylor NF, et al. Strength training can be enjoyable and beneficial for adults with cerebral palsy. *Disabil Rehabil*. 2004;26(19):1121–1127. 7
- [33] Taylor NF, Dodd KJ, Larkin H. Adults with cerebral palsy benefit from participating in a strength training programme at a community gymnasium. *Disabil Rehabil*. 2004;26(19):1128–1134. 7
- [34] Terada K, Satonaka A, Terada Y, et al. Training effects of wheelchair dance on aerobic fitness in bedridden individuals with severe athetospastic cerebral palsy rated to GMFCS level V. *Eur J Phys Rehabil Med*. 2017; 53(5):744–750.
- [35] Bakkum AJT, de Groot S, Stolwijk-Swüste JM, et al. Effects of hybrid cycling versus handcycling on wheelchair-specific fitness and physical activity in people with long-term spinal cord injury: a 16-week randomized controlled trial. *Spinal Cord*. 2015; 53(5):395–401.
- [36] Bélanger M, Stein RB, Wheeler GD, et al. Electrical stimulation: can it increase muscle strength and reverse osteopenia in spinal cord injured individuals? *Arch Phys Med Rehabil*. 2000;81(8):1090–1098.
- [37] Bloomfield SA, Mysiw WJ, Jackson RD. Bone mass and endocrine adaptations to training in spinal cord injured individuals. *Bone*. 1996;19(1):61–68. 1
- [38] Brizuela G, Sinz S, Aranda R, et al. The effect of arm-crank exercise training on power output, spirometric and cardiac function and level of autonomy in persons with tetraplegia. *Eur J Sport Sci*. 2020;20(7):926–934.
- [39] Dallmeijer AJ, Hopman MT, Angenot EL, et al. Effect of training on physical capacity and physical strain in persons with tetraplegia. *Scand J Rehabil Med*. 1997; 29(3):181–186.
- [40] de Carvalho DCL, Cliquet A. Energy expenditure during rest and treadmill gait training in quadriplegic subjects. *Spinal Cord*. 2005; 43(11):658–663.
- [41] DiCarlo SE. Improved cardiopulmonary status after a two-month program of graded arm exercise in a patient with C6 quadriplegia. A case report. *Phys Ther*. 1982; 62(4):456–459.
- [42] DiCarlo SE. Effect of arm ergometry training on wheelchair propulsion endurance of individuals with quadriplegia. *Phys Ther*. 1988; 68(1):40–44.
- [43] DiCarlo SE, Supp MD, Taylor HC. Effect of arm ergometry training on physical work capacity of individuals with spinal cord injuries. *Phys Ther*. 1983; 63(7):1104–1107.
- [44] Ditor DS, Kamath MV, MacDonald MJ, et al. Effects of body weight-supported treadmill training on heart rate variability and blood pressure variability in individuals with spinal cord injury. *J Appl Physiol* (1985). 2005; 98(4):1519–1525.
- [45] Dolbow DR, Gorgey AS, Cifu DX, et al. Feasibility of home-based functional electrical stimulation cycling: case report. *Spinal Cord*. 2012; 50(2):170–171.
- [46] Gass GC, Watson J, Camp EM, et al. The effects of physical training on high level spinal lesion patients. *JRM*. 2018;12(2):61–65.
- [47] Giangregorio LM, Webber CE, Phillips SM, et al. Can body weight supported treadmill training increase bone mass and reverse muscle atrophy in individuals with chronic incomplete spinal cord injury? *Appl Physiol Nutr Metab*. 2006;31(3):283–291.
- [48] Gibbons RS, Shave RE, Gall A, et al. FES-rowing in tetraplegia: a preliminary report. *Spinal Cord*. 2014;52 (12):880–886.

- [49] Gibbons RS, Stock CG, Andrews BJ, et al. The effect of FES-rowing training on cardiac structure and function: pilot studies in people with spinal cord injury. *Spinal Cord*. 2016;54(10):822–829.
- [50] Han D-S, Hsiao M-Y, Wang T-G, et al. Association of serum myokines and aerobic exercise training in patients with spinal cord injury: an observational study. *BMC Neurol*. 2016;16(1):142.
- [51] Harnish CR, Daniels JA, Caruso D. Training response to high-intensity interval training in a 42-year-old man with chronic spinal cord injury. *J Spinal Cord Med*. 2017; 40(2):246–249.
- [52] Hjeltnes N, Aksnes AK, Birkeland KI, et al. Improved body composition after 8 wk of electrically stimulated leg cycling in tetraplegic patients. *Am J Physiol*. 1997;273(3Pt 2):R1072–R1079.
- [53] Hopman MT, Dallmeijer AJ, Snoek G, et al. The effect of training on cardiovascular responses to arm exercise in individuals with tetraplegia. *Eur J Appl Physiol Occup Physiol*. 1996;74(1-2):172–179.
- [54] Janssen TWJ, Pringle DD. Effects of modified electrical stimulation-induced leg cycle ergometer training for individuals with spinal cord injury. *J Rehabil Res Dev*. 2008;45(6):819–830.
- [55] Kakebeeke TH, Hofer PJ, Frotzler A, et al. Training and detraining of a tetraplegic subject: high-volume FES cycle training. *Am J Phys Med Rehabil*. 2008; 87(1):56–64.
- [56] Kim D-I, Lee H, Lee B-S, et al. Effects of a 6-week indoor hand-bike exercise program on health and fitness levels in people with spinal cord injury: a randomized controlled trial study. *Arch Phys Med Rehabil*. 2015;96(11):2033–2040.
- [57] Kressler J, Burns PA, Betancourt L, et al. Circuit training and protein supplementation in persons with chronic tetraplegia. *Med Sci Sports Exerc*. 2014;46(7):1277–1284.
- [58] McLean KP, Skinner JS. Effect of body training position on outcomes of an aerobic training study on individuals with quadriplegia. *Arch Phys Med Rehabil*. 1995;76(2):139–150.
- [59] Mercier HW, Picard G, Taylor JA, et al. Gains in aerobic capacity with whole-body functional electrical stimulation row training and generalization to arms-only exercise after spinal cord injury. *Spinal Cord*. 2021;59(1):74–81.
- [60] Mohr T, Podenphant J, Biering-Sorensen F, et al. Increased bone mineral density after prolonged electrically induced cycle training of paralyzed limbs in spinal cord injured man. *Calcif Tissue Int*. 1997; 61(1):22–25.
- [61] Pollack SF, Axen K, Spielholz N, et al. Aerobic training effects of electrically induced lower extremity exercises in spinal cord injured people. *Arch Phys Med Rehabil*. 1989; 70(3):214–219.
- [62] Sipski ML, Delisa JA, Schweer S. Functional electrical stimulation bicycle ergometry: patient perceptions. *Am J Phys Med Rehabil*. 1989;68(3):147–149.
- [63] Valent LJM, Dallmeijer AJ, Houdijk H, et al. Effects of hand cycle training on physical capacity in individuals with tetraplegia: a clinical trial. *Phys Ther*. 2009;89(10):1051–1060.
- [64] Xi J, Jiang H, Zhang N, et al. Respiratory muscle endurance training with normocapnic hyperpnoea for patients with chronic spinal cord injury: a pilot short-term randomized controlled trial. *J Rehabil Med*. 2019;51(8):616–620.
- [65] De Carvalho DCL, Martins CL, Cardoso SD, et al. Improvement of metabolic and cardiorespiratory responses through treadmill gait training with neuromuscular electrical stimulation in quadriplegic subjects. *Artif Organs*. 2006;30(1):56–63.
- [66] Borg G. Borg's perceived exertion and pain scales. Champaign, IL: Human Kinetics; 1998.
- [67] Hitzig SL, Eng JJ, Miller WC, et al. An evidence-based review of aging of the body systems following spinal cord injury. *Spinal Cord*. 2011;49(6):684–701.
- [68] Garstang SV, Miller-Smith SA. Autonomic nervous system dysfunction after spinal cord injury. *Phys Med Rehabil Clin N Am*. 2007;18(2):275–296.
- [69] Bhamhani Y. Physiology of wheelchair racing in athletes with spinal cord injury. *Sports Med*. 2002;32(1):23–51.
- [70] Stoller O, de Bruin ED, Schindelholz M, et al. Efficacy of feedback-controlled robotics-assisted treadmill exercise to improve cardiovascular fitness early after stroke: a randomized controlled pilot trial. *J Neurol Phys Ther*. 2015; 39(3):156–165.
- [71] Galen SS, Clarke CJ, McLean AN, et al. Isometric hip and knee torque measurements as an outcome measure in robot assisted gait training. *NeuroRehabilitation*. 2014;34(2):287–295.
- [72] Chang WH, Kim MS, Huh JP, et al. Effects of robot-assisted gait training on cardiopulmonary fitness in subacute stroke patients: a randomized controlled study. *Neurorehabil Neural Repair*. 2012;26(4):318–324.
- [73] Mills PB, Krassioukov A. Autonomic function as a missing piece of the classification of paralympic athletes with spinal cord injury. *Spinal Cord*. 2011; 49(7):768–776.
- [74] Solinsky R, Draghici A, Hamner JW, et al. High-intensity, whole-body exercise improves blood pressure control in individuals with spinal cord injury: a prospective randomized controlled trial. *PLoS One*. 2021;16(3):e0247576.
- [75] Edwards WB, Schnitzer TJ, Troy KL. Bone mineral loss at the proximal femur in acute spinal cord injury. *Osteoporos Int*. 2013; 24(9):2461–2469.
- [76] Wafa HA, Wolfe CDA, Emmett E, et al. Burden of stroke in Europe: thirty-year projections of incidence, prevalence, deaths, and disability-adjusted life years. *Stroke*. 2020; 51(8):2418–2427.
- [77] Pedersen BK, Saltin B. Exercise as medicine – evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scand J Med Sci Sports*. 2015; 25 Suppl 3(Suppl 3):1–72.

Appendix

Appendix 1: example of the search strategy used for the scoping review in PubMed

For each diagnosis, the search was performed individually resulting in six separate searches

("stroke"[MeSH Terms])

("Brain Injuries, Traumatic"[MeSH Terms])

((("Quadriplegia"[MeSH Terms]) OR ("Spinal Cord Injuries"[MeSH Terms]))

((("Cerebral Hemorrhage"[MeSH Terms]) OR ("Spina Bifida Cystica"[MeSH Terms]) OR ("Meningomyelocele"[MeSH Terms]) OR ("Meningocele"[MeSH Terms]))

("Cerebral Palsy"[MeSH Terms])

("Chronic Disease"[MeSH Terms])

AND

("Adult"[MeSH Terms])

AND

((("exercise"[MeSH Terms]) OR ("physical fitness"[MeSH Terms]))

no limit to year of publication

Filter: English, German