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

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REVIEW ARTICLE



# 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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Physical activity; severe motor impairment; scoping review; nervous system lesion; physiology; psychology

## 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,

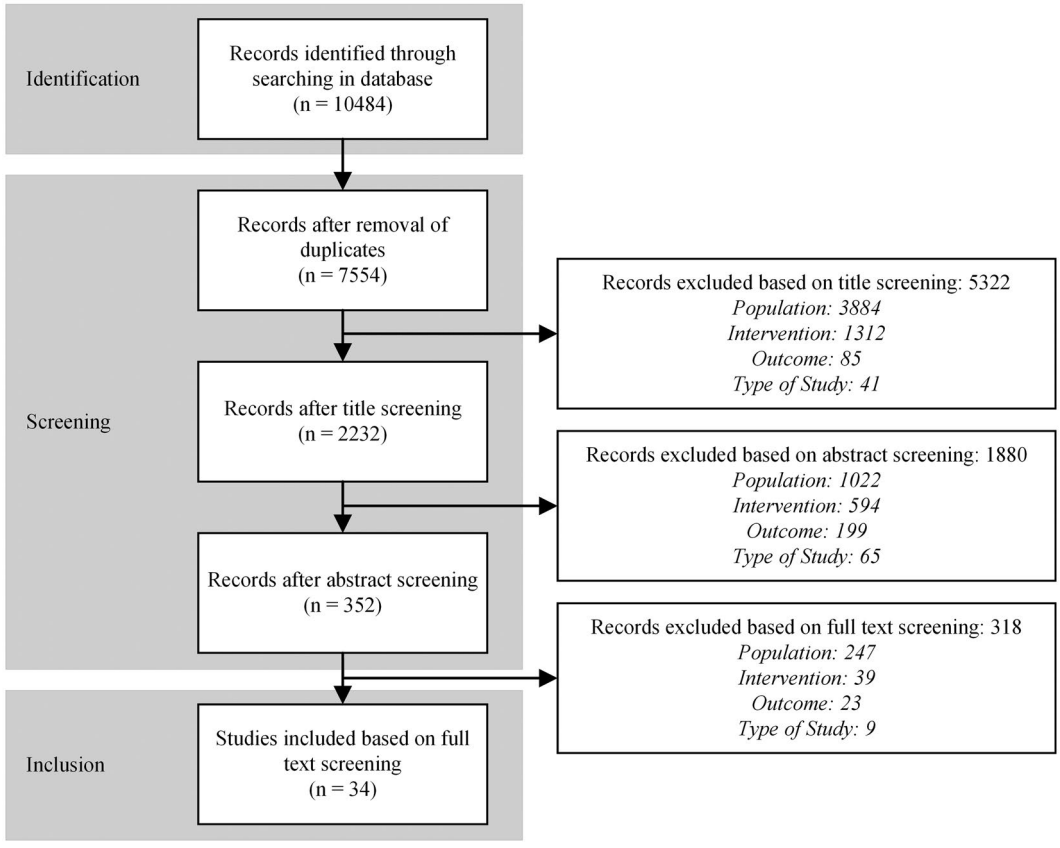


**Figure 1.** Flowchart of search strategy (italic fonts are the reasons for exclusion).

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

| | | Intervention | Participants | | Change in outcomes related to general health |
|---|---|---|---|---|---|
| Reference | 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[†]<br>Number of male subjects[†], diagnosis | Outcomes related to general health | *Italic: based on statistical analysis* |
| Allen et al. 2004 [32] | Pre-post cohort | Strength, equipment from community gymnasium, 10 weeks, 2×/week | 7 (10), 44 years<br>3♀, CP | Qualitative outcomes | Perceived strength: increased |
| Bakkum et al. 2015 [35] | Randomized controlled trial | Endurance, FES cycling and arm ergometer, 16 weeks, 2×/week | 8 (20), 49 years<br>8♀, SCI | Oxygen consumption<br>Power output<br>Heart rate<br>PROM (PASIPD) | *$VO_2$max: no change*<br>*peakPO: no change*<br>*restingHR: reduced*<br>*submaxHR: no change*<br>*maxHR: no change*<br>*PASIPD: increased* |
| Bélanger et al. 2000 [36] | Pre-post cohort | Endurance & strength, FES, 24 weeks, 5×/week | 14 (14), 32 years<br>11♀, SCI | BMD<br>Strength | *BMD: increased*<br>*strength: increased* |
| Bloomfield et al. 1996 [37] | Randomized controlled trial | Endurance, FES cycling, 9 months, 3×/week | 11 (17), 32 years<br>5♀, SCI | BMD | *BMD: increased* |
| Brizuela et al. 2020 [38] | Pre-post cohort | Endurance, arm ergometer, 8 weeks, 2×/week | 11 (11), 37 years<br>8♀, SCI | Power output<br>Heart rate | *peakPO: increased*<br>*submaxHR: no change* |
| Dallmeijer et al. 1997 [39] | Pre-post cohort | Endurance & strength, wheelchair rugby, 6 months, 1×/week | 24 (24), 32 years<br>8♀, SCI | Oxygen consumption<br>Power output<br>Heart rate<br>Strength | *$VO_2$max: no change*<br>*peakPO: no change*<br>*submaxHR: no change*<br>*strength: increased* |
| de Carvalho & Cliquet 2005 [40] | Randomized controlled trial | Endurance, body weight supported walking with FES, 6 months, 2×/week | 21 (21), 32 years<br>21♀, SCI | Oxygen consumption | *$VO_2$max: no change* |
| Di Carlo 1982 [41] | Pre-post case study | Endurance, arm ergometer, 8 weeks, 3×/week | 1 (1), 24 years<br>1♀, SCI | Body mass/composition<br>Oxygen consumption<br>Power output<br>Heart rate | $VO_2$max: increased<br>peakPO: increased<br>submaxHR: decreased<br>body mass: no change |
| Di Carlo 1983 [43] | Pre-post cohort | Endurance, arm ergometer, 5 weeks, 3×/week | 4 (4), 24 years<br>4♀, SCI | Oxygen consumption<br>Power output | $VO_2$max: increased<br>peakPO: increased |
| Di Carlo 1988 [42] | Pre-post cohort | Endurance, arm ergometer, 8 weeks, 3×/week | 8 (8), 24 years<br>8♀, SCI | Oxygen consumption<br>Power output<br>Heart rate | *$VO_2$max: increased*<br>*peakPO: increased*<br>*submaxHR: decreased* |
| Ditor et al. 2005 [44] | Pre-post cohort | Endurance, body weight supported walking with manual assistance, 6 months, 3×/week | 8 (8), 28 years<br>6♀, SCI | Heart rate<br>Blood pressure | *restingHR: reduced*<br>*blood pressure: no change* |
| Dolbow et al. 2012 [45] | Pre-post case study | Endurance, FES cycling, 9 weeks, 3×/week | 1 (1), 64 years<br>1♀, SCI | Body mass/composition<br>BMD<br>PROM (QoL) | body fat: decrease<br>lean body mass: increased<br>BMD: no change<br>QoL: increased |
| Gass et al. 1980 [46] | Pre-post cohort | Endurance, wheelchair ergometer, 7 weeks, 5×/week | 7 (7), 34 years<br>not specified, SCI | Body mass/composition<br>Oxygen consumption<br>Heart rate | *$VO_2$max: increased*<br>*maxHR: no change*<br>*body mass: no change* |
| Giangregorio et al. 2006 [47] | Pre-post cohort | Endurance, body weight supported walking with manual assistance, 1 year, 3×/week | 13 (13), 29 years<br>11♀, SCI | Body mass/composition<br>BMD<br>qualitative outcomes | *lean body mass: increased*<br>*BMD: no change*<br>perceived physical well-being: increased |

(*Continued*)

**Table 2.** Continued.

| | | Intervention | Participants | | |
|---|---|---|---|---|---|
| Reference | 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[†]<br>Number of male subjects[†], diagnosis | Outcomes related to general health | Change in outcomes related to general health<br>*Italic: based on statistical analysis* |
| Gibbons et al. 2014 [48] | Pre-post cohort | Endurance & strength, FES rowing and FES leg conditioning, 1 year, 7×/week | 8 (8), 31 years<br>4♀, SCI | Power output<br>Qualitative outcomes | peakPO: increased<br>averagePO: increased<br>perceived physical well-being: increased |
| Gibbons et al. 2016 [49] | Pre-post cohort | Endurance & strength, FES rowing and FES leg conditioning, 8 weeks, 7×/week | 3 (5), 31 years<br>1♀, SCI | Oxygen consumption<br>Power output<br>Heart rate | *$VO_2$max: increased*<br>*peakPO: increased*<br>*averagePO: increased*<br>*maxHR: 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<br>8♀, variable chronic diseases* | Qualitative outcomes | perceived psychological well-being: increased |
| Han et al. 2016 [50] | Pre-post cohort | Endurance, arm ergometer, 12 weeks, 3×/week | 6 (11), 40 years[#]<br>11♀[#], SCI | Body mass/composition<br>Oxygen consumption<br>Heart rate<br>Blood pressure | *$VO_2$max: no change*<br>*restingHR: no change*<br>*maxHR: no change*<br>*blood pressure: no change*<br>*Body mass: no change* |
| Harnish et al. 2017 [51] | Pre-post case study | Endurance, arm ergometer, 14 weeks, 2–3×/week | 1 (1), 42 years<br>1♀, SCI | Body mass/composition<br>Oxygen consumption<br>Power output | $VO_2$max: increased<br>peakPO: increased<br>averagePO: increased<br>body fat: decreased |
| Hjeltnes et al. 1997 [52] | Pre-post cohort | Endurance, FES cycling, 8 weeks, 7×/week | 5 (5), 35 years<br>5♀, SCI | Body mass/composition<br>BMD<br>Oxygen consumption | *$VO_2$max: increased*<br>*body fat: decreased*<br>*lean body mass: increased*<br>*BMD: no change* |
| Hopman et al. 1996 [53] | Pre-post cohort | Endurance & strength, wheelchair rugby, 6 months, 1×/week | 21 (21), 32 years<br>14♀, SCI | Oxygen consumption<br>Power output<br>Heart rate | *$VO_2$max: no change*<br>*peakPO: no change*<br>*maxHR: no change* |
| Janssen & Pringle 2008 [54] | Pre-post cohort | Endurance, FES cycling, 6 weeks, 2–3×/week | 6 (6), 36 years<br>6♀, SCI | Oxygen consumption<br>Power output<br>Heart rate | *$VO_2$max: increased*<br>*peakPO: increased*<br>*maxHR: increased* |
| Kakebeeke et al. 2008 [55] | Pre-post case study | Endurance, FES cycling, 1 year, 5×/week | 1 (1), 31 years<br>1♀, SCI | BMD<br>Oxygen consumption<br>Power output<br>Heart rate | $VO_2$max: increased<br>peakPO: increased<br>maxHR: increased<br>BMD: increased |
| Kim et al. 2015 [56] | Randomized controlled trial | Endurance, arm ergometer, 6 weeks, 3×/week | 13 (15), 33 years<br>8♀, SCI | Body mass/composition<br>Oxygen consumption<br>Strength | *$VO_2$max: increased*<br>*waist circumference: decreased*<br>*BMI: decreased*<br>*strength: increased* |
| Kressler et al. 2014 [57] | Randomized controlled trial | Endurance & strength, circuit resistance training, 26 weeks, 3×/week | 11 (11) 42 years<br>9♀, SCI | Body mass/composition<br>Oxygen consumption<br>Strength | *$VO_2$max: increased*<br>*body mass: increased*<br>*strength: increased* |

(*Continued*)

**Table 2.** Continued.

| Reference | Study design | Intervention: Type of training, form of training, target duration per participant, target training frequency | Participants: Number of participants fulfilling inclusion criteria (total number of participants), mean age[†]<br>Number of male subjects[†], diagnosis | Outcomes related to general health | Change in outcomes related to general health<br>*Italic: based on statistical analysis* |
|---|---|---|---|---|---|
| McLean & Skinner 1995 [58] | Pre-post cohort | Endurance, arm ergometer, 10 weeks, 3×/week | 14 (14), 34 years<br>not specified, SCI | Body mass/composition<br>Oxygen consumption<br>Power output | *$VO_2$max: increased*<br>*peakPO: increased*<br>*restingHR: increased*<br>*body mass: no change* |
| Mercier et al. 2021 [59] | Pre-post cohort | Endurance, FES rowing, 6 months, 3×/week | 15 (27), 30 years[#]<br>26♀[#], SCI | Oxygen consumption<br>heart rate | *$VO_2$max: increased*<br>*maxHR: no change* |
| Mohr et al. 1997 [60] | Pre-post cohort | Endurance, FES cycling, 1 year, 3×/week | 6 (10), 35 years[#]<br>8♀[#], SCI | BMD<br>Oxygen consumption<br>Power output | *$VO_2$max: increased*<br>*peakPO: increased*<br>*BMD: increased* |
| Pollack et al. 1989 [61] | Pre-post cohort | Endurance, FES cycling, 13–28 weeks, 3×/week | 7 (11), 27 years<br>4♀, SCI | Oxygen consumption<br>Heart rate<br>Blood pressure | *$VO_2$max: increased*<br>*restingHR: no change*<br>*maxHR: increased*<br>*blood pressure: decreased* |
| Sipski et al. 1989 [62] | Retrospective cohort | Endurance, FES cycling, 1.5 months to 2.5 years, frequency not stated | 34 (52), 40 years[#]<br>37♀[#], SCI | Qualitative outcomes | perceived physical and psychological well-being: increased |
| Taylor et al. 2004 [33] | Pre-post cohort | Strength, resistance strength training with various gym equipment, 10 weeks, ×/week | 7 (10), 27 years[#]<br>7♀[#], CP | Strength | *strength: increased* |
| Terada et al. 2017 [34] | Pre-post cohort | Endurance, wheelchair dancing supported by able-bodies person, 1 year, 2–3×/week | 6 (6), 40 years<br>2♀, CP | Oxygen pulse | *$O_2$P: increased* |
| Valent et al. 2009 [63] | Pre-post cohort | Endurance, arm ergometer, 8–12 weeks, 2–3×/week | 15 (15), 29 years<br>unclear, SCI | Oxygen consumption<br>Power output<br>Heart rate<br>Strength | *$VO_2$max: increased*<br>*peakPO: increased*<br>*submaxHR: no change*<br>*strength: increased* |
| Xi et al. 2019 [64] | Randomized controlled trial | Strength, respiratory muscle training, 4 weeks, 5x/week | 10 (18), 53 years<br>not specified, SCI | PROM (PHQ-9 & SGRQ) | *PHQ-9: decreased*<br>*SGRQ: decreased* |

BMD: bone mineral density; BMI: body mass index; CP: cerebral palsy; FES: functional electrical stimulation; HR: heart rate; $O_2$P: 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; $VO_2$max: 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.

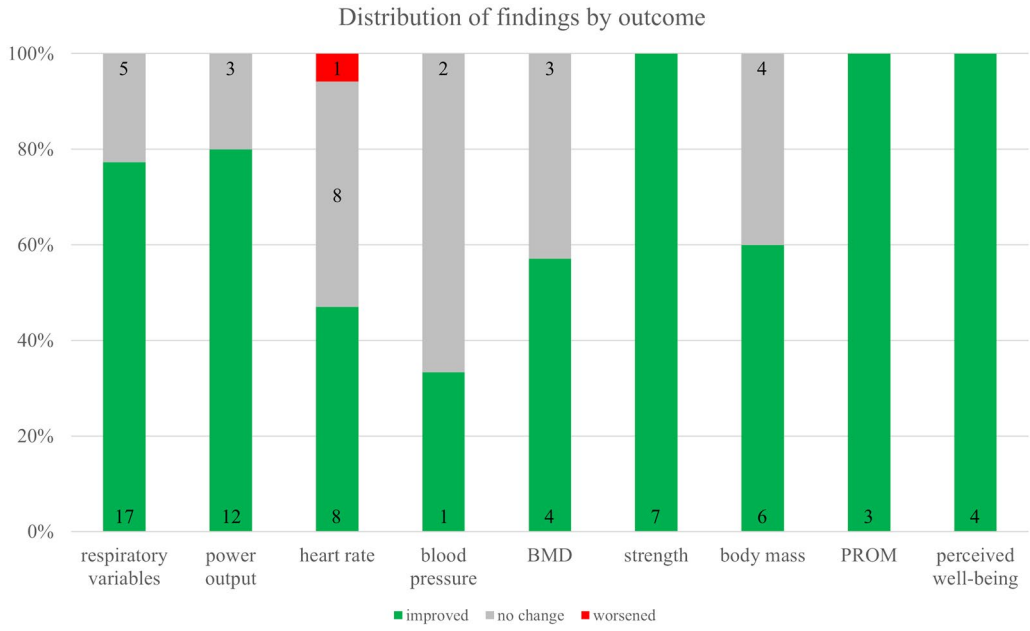


**Figure 2.** Percentage of articles that found improved, not changed, or worsened outcomes after a PA intervention grouped according to outcome category. Data labels indicate the absolute number of articles. BMD: bone mineral density, PROM: patient-reported outcome measures.

[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 ($O_2$P), a relative measure of stroke volume, during a wheelchair dance intervention and found increased $O_2$P 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 where 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 $O_2$P, 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. Am 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 contributionsww

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.

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# 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