REVIEW ARTICLE

Home and Community-Based Physical Activity for Individuals with Spinal Cord Injury: A Systematic Review

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ABSTRAK

Aktiviti fizikal berasaskan rumah dan komuniti (HCPA) menawarkan pendekatan yang mudah diakses untuk meningkatkan pemulihan fungsi dan tahap berdikari dalam kalangan individu yang mengalami kecederaan saraf tunjang (SCI). Walaupun berpotensi, bukti sedia ada masih belum konklusif kerana kepelbagaian reka bentuk kajian, populasi dan intervensi yang digunakan. Tinjauan sistematik ini bertujuan menilai variasi dalam ciri-ciri peserta dan strategi intervensi dalam program HCPA bagi individu SCI, menilai keberkesanannya serta mengenal pasti jurang penyelidikan. Carian sistematik telah dijalankan menerusi pangkalan data Cochrane, Medline, PubMed, ScienceDirect dan Scopus bagi mengenal pasti kajian terkawal rawak (RCT) yang diterbitkan antara Januari 1994 hingga Januari 2024. Istilah carian menggabungkan Medical Subject Headings dan istilah teks bebas bagi SCI, senaman rumah atau komuniti, serta hasil prestasi fizikal. Daripada 8,370 rekod, hanya lapan RCT memenuhi kelayakan selepas saringan ketat. Kualiti kajian dinilai menggunakan skala 'Physiotherapy Evidence Database'. Kajian RCT yang disertakan menunjukkan kualiti metodologi sederhana serta kepelbagaian ketara dalam ciri demografi, profil kecederaan, intervensi dan ukuran hasil. Bukti telah menunjukkan bahawa HCPA boleh dilaksanakan, malah dapat memberi peningkatan sederhana dalam kecergasan fizikal serta hasil fungsi. Program lazimnya melibatkan 2-4 sesi seminggu, dengan tempoh 30 hingga 60 minit setiap sesi pada intensiti sederhana, yang merangkumi latihan aerobik, rintangan dan latihan kemahiran penggunaan kerusi roda. HCPA merupakan pendekatan yang praktikal dan agak berkesan untuk individu dengan SCI. Walau bagaimanapun, protokol yang lebih seragam dan disesuaikan mengikut keperluan individu amat diperlukan. Penyelidikan pada masa hadapan perlu memberi keutamaan kepada RCT berskala besar dan berkualiti tinggi bagi mewujudkan garis panduan berasaskan bukti untuk pelaksanaan yang mampan dalam konteks pemulihan SCI di rumah dan komuniti.

Kata kunci: *Aktiviti fizikal; kecederaan saraf tunjang; pemulihan komuniti; pemulihan fungsi; senaman berasaskan rumah*

ABSTRACT

Home and community-based physical activity (HCPA) offer an accessible approach to enhancing functional recovery and independence in individuals with spinal cord injury (SCI). Despite its potential, evidence remains inconclusive due to heterogeneity in study designs, populations, and interventions. This review aimed to evaluate the variability in participant characteristics and intervention strategies in HCPA programs for SCI, assess their effectiveness, and identify research gaps. A systematic search was conducted in Cochrane, Medline, PubMed, ScienceDirect and Scopus for randomised controlled trials (RCTs) published between January 1994 and January 2024. Search terms combined Medical Subject Headings and free-text terms for SCI, home or community exercise and physical performance outcomes. From 8,370 records, eight RCTs met eligibility after rigorous screening. Study quality was assessed using the Physiotherapy Evidence Database scale. The included RCTs demonstrated moderate methodological quality and notable heterogeneity in demographic characteristics, injury profiles, interventions and outcome measures. Evidence suggests HCPA is feasible and yields moderate improvements in physical fitness and functional outcomes. Programs typically involved 2-4 sessions weekly, 30-60 minutes each, at moderate intensity, incorporating aerobic, resistance and wheelchair skills training. HCPA is practical and moderately effective for individuals with SCI. However, standardised, individualised protocols are urgently required. Future research should prioritise large-scale, high-quality RCTs to establish evidence-based guidelines for sustainable implementation in home and community rehabilitation contexts.
Keywords: Community rehabilitation; functional recovery; home-based exercise; physical activity; spinal cord injury

INTRODUCTION

Spinal cord injury (SCI) is a catastrophic condition that disrupts motor, sensory and autonomic functions, substantially affecting physical capacity and quality of life (QoL) (Hisham et al. 2022a). Globally, over 15 million individuals live with SCI, with an estimated 250,000–500,000 new cases occurring annually (Lu et al. 2024). Meanwhile, in the Asian region, East Asia had one of the highest reported injuries, with 13 cases per 100,000 cases and a positive annual percentage change of 0.7%, indicating an upward trend in incidence rates (Yokota et al. 2024). Conversely, Southeast Asia had a lower incidence of 7 per 100,000, accompanied by a decreasing trend (-0.6% annual change) (Ding et al. 2022).

Individuals with SCI experience wide-ranging secondary health complications and functional limitations, including mobility restrictions, heightened risk of cardiometabolic diseases, pressure injuries, and declines in psychosocial well-being (Budd et al. 2022; Di Giulio et al. 2024; Fryer et al. 2023; Hisham et al. 2025; Raguindin et al. 2021). To combat these issues, physical activity has been increasingly recognised for its role in improving functional recovery and enhancing both physical and psychological health among populations with neurological and chronic conditions (Azizan 2024; Azizan et al. 2023).

However, rehabilitation services that provide education and training of HPA remain largely facility-based, resource-intensive and short-term, creating substantial barriers after discharge (Hisham et al. 2022b; Manaf et al. 2018; Manaf et al. 2021). Many individuals encounter transportation challenges, reliance on caregivers, long waiting times and the high cost of extended facility care (Grossmann et al. 2021; Jeyathevan et al. 2020). Specialised equipment requirements and inconsistent availability of community-based support further limit long-term engagement (Declerck et al. 2021; Rayes et al. 2022). Consequently, rehabilitation models that extend beyond traditional clinical environments are needed to provide more accessible, sustainable and context-appropriate options. These benefits underscore the potential value of home and community-based physical activity (HCPA) approaches for people with SCI.

Home-based physical activity refers to a variety of physical activities conducted within the domestic or family environment, rather than the external facilities (Zhou et al. 2025). This category also includes tele-exercise and remotely delivered programs, provided that the primary activities occur in the home setting, with or without virtual supervision. In contrast, community-based physical activity describes the programs and initiatives that promote physical activity within a specific community, often through accessible group settings like community centres or local parks (Sivaramakrishnan et al. 2023). Together, these approaches constitute HCPA interventions. This review specifically focuses on adults with SCI across the post-rehabilitation discharge and chronic stages, where long-term self-managed rehabilitation becomes critical. HCPA programs offer flexible, personalised, and often lower-cost alternatives that may enhance autonomy, continuity, social participation, and real-world functional application to this group (Barria et al. 2025; Koh & Mortenson 2024). Despite their promise, evidence supporting HCPA for individuals with SCI remains limited and fragmented. Existing reviews have predominantly examined facility-based or supervised clinical interventions (Peters et al. 2021; Vachova et al. 2024; van der Scheer et al. 2021), often merging community- or home-based approaches into broader categories. This blurs distinctions between intervention types and leaves critical questions unanswered regarding the unique effectiveness and feasibility of decentralised, real-world models.

Although emerging randomised controlled trials (RCTs) suggest that HCPA interventions, including home exercise, tele-rehabilitation and community-based fitness programs, are feasible and beneficial, the evidence remains sparse (Froehlich-Grobe et al. 2022; Nightingale et al. 2018). To date, no review has exclusively synthesised RCTs evaluating HCPA for individuals with SCI or captured the recent growth of remote and community-integrated rehabilitation strategies.

Following the International Classification of Functioning, Disability and Health (ICF) framework (World Health Organisation 2001), this review is informed by situating HCPA outcomes across body functions (strength, aerobic capacity), activities (functional performance) and participation (community engagement, QoL) (Hadar-Frumer et al. 2023). Considering contextual factors enables a comprehensive understanding of facilitators and barriers influencing the implementation of HCPA. Through this lens, the review focused on generating evidence-based recommendations for scalable, sustainable exercise programs that align with the lived environments of individuals with SCI.

Guided by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodological standards, this systematic review aimed to rigorously synthesise evidence on the effects of HCPA interventions among SCI individuals. In line with Population, Intervention, Comparison and Outcomes (PICO) framework, this review evaluated the effects of different exercise modalities (aerobic vs. resistance training) and delivery formats (supervised vs. unsupervised; in-person vs. remote) compared with usual care or alternative interventions. The review also aimed to identify optimal exercise prescription parameters using the frequency, intensity, time and type (FITT) principle while examining feasibility outcomes such as adherence, satisfaction and strategies for overcoming participation barriers.

MATERIAL AND METHODS

Search Strategy

This systematic review was conducted in compliance with the PRISMA 2020 guidelines. This study was also registered with PROSPERO (CRD 42024542169). A comprehensive search strategy was applied across five major health-related databases, including Cochrane, Medline, PubMed, ScienceDirect and Scopus, covering the period from January 1994 to January 2024.

The broad search period was chosen because earlier RCTs laid the foundational principles of exercise prescription in SCI, many of which remain clinically relevant today. Although technology and rehabilitation approaches have evolved, physiological training responses and functional challenges in SCI have remained largely consistent. Including older studies prevented the loss of valuable evidence, allowed long-term trends to be captured and supported a more complete and coherent understanding of the development of exercise-based interventions over time.

The search combined Medical Subject Headings (MeSH) and free-text terms: ("spinal cord injury") AND ("home" OR "community") AND ("exercise" OR "physical activity" OR "intervention") AND ("physical capacity" OR "physical fitness" OR "physical performance"). To ensure completeness, bibliographies of relevant articles were also screened for additional eligible studies.

Study Eligibility Criteria

Studies were included if they (i) involved participants with SCI; (ii) examined the effects of home- or community-based exercise interventions; (iii) reported on outcomes related to physical capacity, physical fitness, or physical performance; (iv) RCTs; and (v) were available in English.

Studies Exclusion Criteria

Studies were excluded if they involved non-randomised designs, non-SCI populations, animal models, non-English publications, non-peer-reviewed sources, or lacked full-text data. Facility-based programs, conference proceedings, reviews, and studies without relevant outcomes were also excluded to ensure methodological rigor and relevance.

Data Extraction

Data extraction was performed manually using a data extraction form that captured key study information, including author, year, study design, sample characteristics, intervention details, comparison group, outcome measures and main findings. The process adhered strictly to PRISMA 2020 guidelines to ensure methodological transparency and reproducibility. Two reviewers independently extracted data and discrepancies were resolved through discussion until consensus was reached, with the senior author moderating the consensus sessions to ensure accuracy and consistency.

Quality Assessment of the Study

The quality of the included studies was appraised using the Physiotherapy Evidence Database (PEDro) scale, which assessed the methodological quality of clinical trials (Cashin & McAuley 2020). The PEDro scale included items on random allocation, concealed allocation, baseline comparability, blinding, follow-up, intention-to-treat (ITT) analysis and statistical analysis. Each study was independently assessed by two reviewers and any discrepancies were resolved through consensus discussion with senior authors.

Data Synthesis

Data from the included studies were synthesised narratively due to substantial heterogeneity in study design, participant characteristics, intervention types and outcome measures. Quantitative pooling or meta-analysis was not attempted because the variability in exercise modalities, program duration, intensity and measurement tools precluded meaningful statistical aggregation. Instead, a descriptive synthesis was conducted to summarise findings on physical capacity, functional performance, and fitness outcomes across home- and community-based interventions. This qualitative approach aligned with PRISMA 2020 recommendations when data heterogeneity or incomplete reporting limited quantitative integration.

The FITT framework was applied by

systematically extracting the frequency, intensity, time and type of exercise prescribed in each study. Frequency referred to the number of weekly sessions, while intensity was standardised into light, moderate or vigorous using reported heart rate, Maximal Oxygen Consumption (VO_2 max), Rate of Perceived Exertion (RPE) or resistance loads. Session duration and interventions were also extracted to enable consistent comparison across highly diverse studies and helped identify the exercise dosages most strongly associated with improvements in physical capacity and functional outcomes.

RESULTS

Study searching

The initial search identified 8,370 records across five databases. After removing 413 duplicates, 7,957 studies were screened, with 1,403 abstracts and 12 full texts reviewed. Ultimately, eight RCTs met all eligibility criteria and were included in the final analysis, as outlined in the PRISMA flowchart. Figure 1 showed the PRISMA flowchart of the study searching and selection procedure. Of these, four studies focused on home-based physical activity interventions and four involved community-based physical activity programs.

Participants' Characteristics of Home-Based Physical Activity Program

(a) Age and years since injury

Table 1 presented the participants' demographic and clinical characteristics, including age, years since injury (YSI), gender distribution, injury level and severity based on the American Spinal Injury Association (ASIA) Impairment Scale (AIS

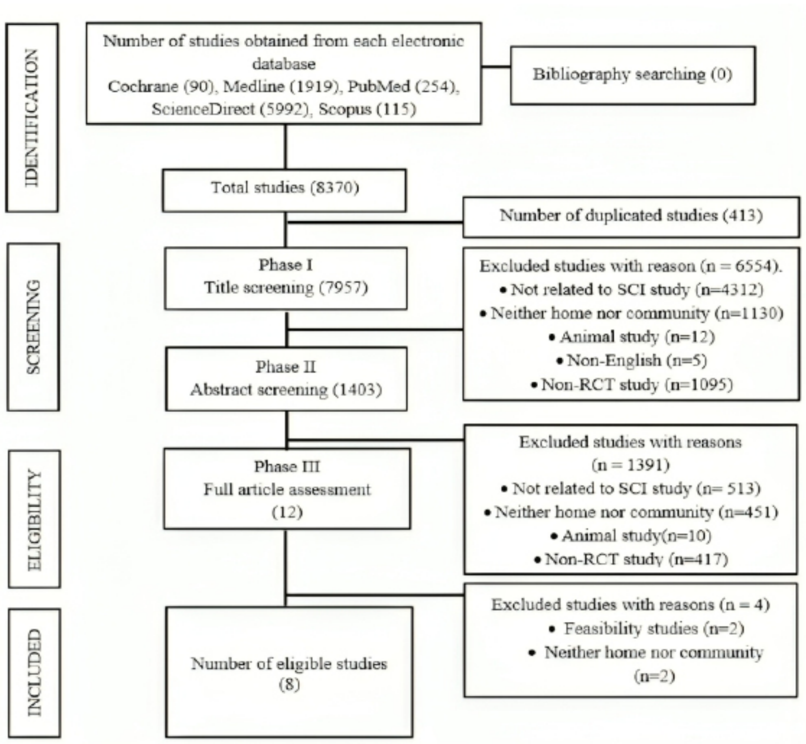

FIGURE 1: Flowchart of the study searching and selection procedure (PRISMA)

TABLE 1: Participants' characteristics of the included studies of home and community physical activity (HCPA) programs

Author	Age Mean (SD)	Years Since Injury Mean (SD)	Gender (n)	Level of SCI (n)
Home-based Physical Activity				
Nightingale et al. (2018)	INT: 46 (6) y/o CON: 48 (10) y/o	INT: 14 (11) yrs CON: 20 (10) yrs	INT: M 9, F 4 CON: M 6, F 2	INT: T6: 5, <T6:8 CON: T6: 4, <T6: 4
Wouda et al. (2018)	HIIT: 50 (15) y/o MIT: 34 (15) y/o CON: 41 (19) y/o	HIIT: 68 (31) days MIT: 65 (34) days CON: 73 (24) days	HIIT: M 8, F 2 MIT: M 8, F 2 CON: M 9, F 1	HIIT: C1–C8: 7, T1–T5: 1, L1–L5: 2 MIT: C1–C8: 4, T1–T5: 1, T6–T12: 3, L1–L5: 2 CON: C1–C8: 7, T1–T5: 1, L1–L5: 1, S1–S5: 1
Nightingale et al. (2017)	INT: 46 (6) y/o CON: 48 (10) y/o	INT: 14 (11) yrs CON: 20 (10) yrs	INT: M 9, F 4 CON: M 6, F 2	INT: T6: 5, <T6: 8 CON: T6: 4, <T6: 4
Mulroy et al. (2011)	INT: 47 (9) y/o CON: 47 (12) y/o	INT: 17.9 (9.2) yrs CON: 22.3 (11.8) yrs	INT: M 31 CON: M 26	INT: High para: 27, Low para: 13 CON: High para: 16, Low para: 24
Community-based Physical Activity				
Worobey et al. (2016)	INT: 40 (11.4) y/o CON: 41 (12.4) y/o	INT: 13.5 (11.8) yrs CON: 12.9 (12.5) yrs	INT: M 32 CON: M 37	INT: Paraplegia: 29 CON: Paraplegia: 31
Kirby et al. (2016)	INT: 48.1 (13.6) y/o CON: 47.1 (12.6) y/o	INT: 16.6 (12.9) yrs CON: 18.2 (13.0) yrs	INT: M 51 (96.2%) CON: M 50 (94.3%)	INT: Tetraplegia: 4; Para (L): 3; Para (T): 46 CON: Tetraplegia: 9; Para (L): 6; Para (T): 38
Pelletier et al. (2015)	INT: 40.4 (11.6) y/o CON: 45.9 (11.5) y/o	INT: 15 (8.52) yrs CON: 9.25 (10.0) yrs	INT: M 12, F 0 CON: M 9, F 2	INT: C3–T10 CON: C1–T11
Totosy de Zepetnek et al. (2015)	INT: 39 (11) y/o CON: 42 (13) y/o	INT: 15 (10) yrs CON: 9 (10) yrs	INT: M 12, F 0 CON: M 9, F 2	INT: C3–T10 CON: C1–T11

INT: Intervention; CON: Control; y/o: years old; YSI: Years since injury; M: Male; F: Female; C: Cervical; T: thoracic; L: Lumbar; S: Sacral; AIS: ASIA Impairment Scale; HIIT: High-intensity interval training; MIT: Moderate-intensity training.

classification). Across studies, the mean age ranged from the mid-30s to late-40s, consistent with the demographic profile of long-term SCI survivors. Nightingale et al. (2017, 2018) reported mean ages of approximately 46 years in intervention groups and 48 years among controls, whereas Mulroy et al. (2011) observed a comparable mean of 47 years. Wouda et al. (2018) presented a wider range (34–50 years), reflecting the inclusion of both younger and older adults with incomplete injuries. Years since injury averaged 14 to 22 years, indicating a chronically injured cohort. This chronicity underscores the feasibility and clinical relevance of prescribing home-based exercise well beyond the acute rehabilitation phase, offering secondary-prevention benefits for long-term health maintenance.

(b) Gender distribution

Male predominance was evident across all studies, mirroring global SCI epidemiology. In Nightingale et al. (2017, 2018), males comprised roughly 70% of participants, while Mulroy et al. (2011) included exclusively male subjects, reflecting higher injury incidence among men due to occupational and vehicular risk exposure. Wouda et al. (2018) maintained a similar pattern, with males representing 80–90% of each study arm. Although consistent with population data, this imbalance highlighted a persistent gap in gender representation.

(c) Level of spinal cord injury

The neurological distribution of injuries extended from cervical to lumbar levels, demonstrating the adaptability of home-based exercise protocols across varying functional capacities. Nightingale et al. (2017, 2018) enrolled participants both above and below T6, ensuring inclusion of individuals with potential autonomic dysreflexia risk as well as those with paraplegia. Mulroy et al. (2011) differentiated participants into high and low paraplegia subgroups, acknowledging the mechanical loading demands on shoulder joints during wheelchair propulsion. Wouda et al. (2018) included ambulatory participants with incomplete cervical and thoracic injuries, extending the application of home-based interventions to those with partial motor recovery. Collectively, the heterogeneity in injury level supports the versatility of individualised exercise prescription, allowing home-based programs to be tailored to functional ability while maintaining safety and therapeutic benefit.

(d) Severity of injury (AIS Classification)

Most participants presented with incomplete injuries, primarily classified as AIS C–D, reflecting residual motor function conducive to voluntary exercise. Nightingale et al. (2017, 2018) reported a majority of AIS A–B in the control and intervention groups, yet still included a meaningful subset of AIS C–D participants capable of performing arm-crank exercises. Wouda et al. (2018) predominantly recruited participants with incomplete AIS D lesions, with only one participant classified as complete (ASIA-A), indicating high ambulatory potential. Mulroy et al. (2011) included a broader spectrum (AIS A–D), enabling assessment of exercise tolerance across severity levels. Overall, these studies demonstrated that both complete and incomplete injuries can benefit from structured, home-based interventions when appropriately adapted for neuromuscular capacity, emphasising the inclusive applicability of such programs within the chronic SCI population.

Participants' Characteristics of Community-Based Physical Activity Program

Table 1 summarised the demographic and clinical characteristics of participants, including age, years since injury, gender distribution, level of SCI and severity of impairment, as classified by the AIS scale.

(a) Age and years since injury

The mean age ranged between 39 and 48 years across studies. Kirby et al. (2016) reported the oldest cohort (48.1 $\pm$ 13.6 years), while Totosy de Zepetnek et al. (2015) observed a slightly younger population (39 $\pm$ 11 years). The years since injury varied from 9 to 18 years, reflecting that participants were well beyond the acute recovery stage. Pelletier et al. (2015) noted that participants averaged 15 years post-injury in the intervention group, indicating sustained interest and feasibility in structured exercise even after extended disability duration.

(b) Gender distribution

Kirby et al. (2016) reported over 95% male representation in both intervention and control groups, whereas Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) included only two to three female participants across all cohorts. Similarly, Worobey et al. (2016) recruited entirely male samples.

(c) Level of spinal cord injury

The neurological level of injury across studies ranged from cervical to thoracic segments, encompassing both tetraplegia and paraplegia.

Kirby et al. (2016) reported that the majority of participants had thoracic paraplegia (n = 46) with smaller subsets of lumbar paraplegia and tetraplegia, reflecting a functionally heterogeneous cohort. Similarly, Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) included participants with injuries from C1–T11, ensuring inclusion of individuals with varying upper-limb capacity and autonomic control. Worobey et al. (2016) recruited only participants with paraplegia, resulting in a more homogeneous group ideal for evaluating wheelchair skills and functional independence. Collectively, these distributions demonstrated the adaptability of community-based programs across different injury levels, with evidence supporting both high- and low-level participants benefiting from structured mobility and exercise interventions.

(d) Severity of injury (AIS Classification)

Most participants were classified as incomplete (AIS C–D), representing those with partial motor preservation capable of voluntary exercise. Pelletier et al. (2015) included a mix of AIS A–D participants, while Totosy de Zepetnek et al. (2015) reported a predominance of incomplete injuries (AIS C–D = 9) compared to complete injuries (AIS A–B = 3) in the intervention group. This distribution supported the inclusion of individuals with varying degrees of neurological completeness and incomplete SCI populations can safely engage in community-based physical activity with appropriate supervision.

Study Characteristics of Home-Based Physical Activity Program

Table 2 outlined the characteristics of RCTs evaluating these programs, including study design, outcome measures, interventions, control conditions and main findings.

(a) Study design and duration

All included studies employed RCT designs, confirming a high methodological standard for evaluating home-based physical activity interventions. The intervention duration ranged from 6-12 weeks. Nightingale et al. (2017, 2018) implemented six-week moderate-intensity programs, while Wouda et al. (2018) and Mulroy et al. (2011) conducted 12-week interventions to assess both physiological and musculoskeletal outcomes.

(b) Sample size

Sample sizes varied from small-scale pilot cohorts to large controlled trials. The smallest sample was reported by Nightingale et al. (2017, 2018) with 21 participants (13 intervention, 8 control), focusing on cardiorespiratory and metabolic adaptations. Wouda et al. (2018) included 30 participants equally distributed among high-intensity interval training (HIIT), moderate-intensity training (MIT) and control groups. Mulroy et al. (2011) conducted the largest trial with 80 participants, targeting upper-limb musculoskeletal health.

(c) Type of outcome measures

Outcome measures spanned physiological, metabolic and psychosocial domains. Nightingale et al. (2018) evaluated health-related quality of life (HRQoL) using SF-36, fatigue and exercise self-efficacy. Wouda et al. (2018) assessed aerobic capacity through peak Maximal Oxygen Consumption (VO_2), 6 Minute Walk Test (6MWT), and activity tracker data, while Mulroy et al. (2011) focused on musculoskeletal pain (WUSPI) and functional shoulder torque. Nightingale et al. (2017) also analysed fasting insulin and HOMA-IR to explore metabolic adaptations.

(d) Intervention characteristics

Nightingale et al. (2017, 2018) prescribed four weekly sessions of 45-minute, moderate-intensity arm-crank exercises using portable ergometers, progressively increasing duration and resistance. Wouda et al. (2018) compared high-intensity interval training (HIIT) (4 x 4-minute bouts at 85–95% HRpeak) and moderate-intensity training

TABLE 2: Characteristics of the included studies of home-based physical activity programs

Author	Study design	Sample size (n)	Type of outcome measure	Intervention group	Control group	Results
Nightingale et al. (2018)	RCT 6-weeks	Intervention: 13 Control: 8	· PCS, SF-36 · MCS, SF-36 · QALY, FSS · Global fatigue · Visual analog fatigue scale, WUSPI, ESES	Home-based moderate-intensity upper-body exercise intervention group · 4 times 45-minute moderate-intensity arm-crank exercise sessions per week for 6 weeks	Lifestyle maintenance	· The intervention group showed clear improvements in overall HRQoL. · Increases in exercise self-efficacy were positively associated with better physical and mental quality-of-life scores, with significant changes in SF-36 PCS ($p = 0.017$), ESE ($p = 0.011$), and FSS ($p = 0.036$).
Wouda et al. (2018)	RCT 12-weeks	Intervention: HIIT: 10, MIT: 10 Control: 10	· Peak VO_2 · RER · Peak HR · Blood lactate · 6MWT · PA level (activity tracker) · IPAQ questionnaire	Home-based aerobic exercise program (i) HIIT · walk/run 2x per week, each lasting for 35 min; 10 min warm-up at 70% of peak HR followed by 4 x 4 min intervals at an intensity of 85–95% of peak HR, interspersed with 3 x 3 min recovery periods at an intensity of 70% of peak HR (ii) MIT · walk/run 3x per week, each lasting for 45 min of continuous activity at an intensity of 70% of peak HR.	Usual treatment	· All three groups (HIIT, MIT, and control) showed increases in peak VO_2 from pre- to post-test. · However, there were no significant between-group differences in physical capacity (peak VO_2 and 6MWT) or physical activity levels (TDEE and daily step count). · Peak VO_2 (L/min): MIT vs HIIT ($p = 0.86$), control vs HIIT ($p = 0.73$). · Peak VO_2 (mL/kg/min): MIT vs HIIT ($p = 0.66$), control vs HIIT ($p = 0.91$). · 6MWT: MIT vs HIIT ($p = 0.96$), control vs HIIT ($p = 0.36$). · TDEE: MIT vs HIIT ($p = 0.58$), control vs HIIT ($p = 0.56$). · Daily step count: MIT vs HIIT ($p = 0.58$), control vs HIIT ($p = 0.56$).

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Author	Study design	Sample size (n)	Type of outcome measure	Intervention group	Control group	Results
Nightingale et al. (2017)	RCT 6 weeks	Intervention: 13 Control: 8		Home-based exercise intervention · 45-minute moderate-intensity arm-crank exercise sessions 4x per week · Each exercise was extended by 5 min per session in the first week (30 to 45 min). · Exercise intensity was also increased · Using a portable desktop arm-crank ergometer in their own home	Lifestyle maintenance	· Intervention group improved (i) functional capacity (VO_2peak and power output), (ii) fasting insulin concentrations, and (iii) HOMA-IR · Home-based provided a considerable volume of structured exercise. · Reduced insulin resistance with a modest increase in energy expenditure and without improvements in body composition. · Serum fasting insulin, INT showed a significant reduction compared to CON ($p = 0.04$), INT: –12.7 ± 18.7 pmol/L, CON: +3.1 ± 10.7 pmol/L · Insulin resistance (HOMA2-IR), INT demonstrated a significant decrease compared to CON ($p = 0.04$), CON: +0.06 ± 0.20, INT: –0.23 ± 0.36
Mulroy et al. (2011)	RCT 12-weeks	Intervention: 40 Control: 40		· The shoulder strengthening and stretching exercise for joint capsules and muscles (i) Warm-up phase · 4 non-resisted active movements (ii) Resistive exercise · 4 exercises performed during the warm-up phase · 3 sets of 8 repetitions for each hypertrophy exercise · 3 sets of 15 repetitions for the endurance exercises · 1- to 2-minute rest interval between sets	1-hour instructional video on shoulder anatomy, injury, and pain management · A handout on the video and an educational brochure regarding shoulder care	· The intervention group demonstrated clear improvements in functional capacity, including higher VO_2 peak and increased power output. · Home-based training delivered a substantial amount of structured exercise, sufficient to elicit cardiometabolic benefits. · The program reduced insulin resistance with only modest changes in energy expenditure and no measurable improvements in body composition. · Serum fasting insulin decreased significantly in the intervention group compared to control ($p = 0.04$; INT: –12.7 ± 18.7 pmol/L vs CON: +3.1 ± 10.7 pmol/L). · Insulin resistance (HOMA2-IR) also decreased significantly ($p = 0.04$; INT: –0.23 ± 0.36 vs CON: +0.06 ± 0.20). · Peak aerobic capacity (VO_2peak) increased significantly in the intervention group, with a mean improvement of 3.4 mL/kg/min ($p \leq 0.001$).

CON: Control group; FSS: Fatigue Severity Scale; ESES: Exercise Self-Efficacy Scale; HIIT: High-intensity interval training; HR: Heart rate; HOMA-IR: Homeostatic Model Assessment for Insulin Resistance; INT: Intervention group; IPAQ: International Physical Activity Questionnaire; MCS SF-36: Mental Component Summary of the Short Form Health Survey; MIT: Moderate-intensity training; QALY: Quality-Adjusted Life Years; QOL: Quality of life; PCS: Physical Component Summary of the Short Form Health Survey ; Peak VO_2: Peak oxygen uptake; RCT: Randomised controlled trial; RER: Respiratory exchange ratio; SF-36: Short Form Health Survey-36; TDEE: Total Daily Energy Expenditure; VO_2peak: Peak volume of oxygen consumption; WUSPI: Wheelchair User's Shoulder Pain Index; 6MWT: Six-minute walk test

(MIT) (continuous 45-minute sessions at 70% HRpeak) walking/running regimens performed two to three times weekly. Mulroy et al. (2011) implemented a comprehensive shoulder rehabilitation program emphasising stretching, hypertrophy, and endurance strengthening using resistance bands and controlled repetitions.

(e) Control conditions

Control groups across studies typically maintained lifestyle or educational routines without structured exercise. Nightingale et al. (2017, 2018) provided lifestyle maintenance guidance, while Wouda et al. (2018) used a "usual treatment" approach allowing spontaneous physical activity. Mulroy et al. (2011) delivered educational materials and instructional videos on shoulder care but excluded active training.

Study Characteristics of Community-Based Physical Activity Program

In Table 3, all four studies employed RCTs designs, demonstrating high methodological rigor in evaluating community-based physical activity interventions among individuals with SCI. The program durations varied from eight weeks to one year, reflecting a range of short-term to longitudinal designs that allowed assessment of both immediate and sustained effects. Shorter interventions, such as the 8-week wheelchair skills training program (WSTP) by Worobey et al. (2016), focused on functional outcomes, whereas longer studies, including Kirby et al. (2016), adopted extended follow-ups to capture long-term functional and psychosocial benefits.

(a) Sample size

Sample sizes across studies were moderate, ranging from 23 participants (Pelletier et al. 2015; Totosy de Zepetnek et al. 2015) to 106 participants (Kirby et al. 2016). These participant numbers provided sufficient power to detect meaningful between-group differences while maintaining feasibility within community settings. The majority of studies achieved balanced group allocation, with intervention and control groups showing comparable baseline characteristics, thereby supporting the internal validity of the findings.

(b) Type of outcome measures

Outcome measures were diverse, capturing both functional performance and physiological adaptations. Worobey et al. (2016) and Kirby et al. (2016) emphasised functional mobility, utilising the Wheelchair Skills Test Questionnaire (WST-Q), Goal Attainment Scale (GAS), and CHART Mobility sub-score to assess improvements in real-world mobility and participation. Conversely, Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) focused on aerobic capacity, muscle strength, and vascular and metabolic health, using parameters such as peak oxygen consumption (VO_2peak), arterial distensibility and body composition indices. This multidimensional assessment highlighted the comprehensive rehabilitative benefits of community-based exercise programs in individuals with SCI.

(c) Intervention characteristics

Intervention approaches varied but shared a focus on structured, supervised and community-integrated participation. Worobey et al. (2016) and Kirby et al. (2016) implemented WSTP, delivered through weekly group sessions or individualised coaching emphasising balance, propulsion and advanced wheelchair handling. In contrast, Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) adopted Physical Activity Guideline (PAG)-based community exercise programs that combined aerobic and resistance training at moderate to vigorous intensity for 16 weeks. Collectively, these interventions promoted self-efficacy, cardiorespiratory endurance, and upper-limb strength, highlighting the adaptability of community-based formats to various functional levels and goals.

TABLE 3: Characteristics of the included studies of community-based physical activity program

Author	Design and duration	Sample size (n)	Type of outcome measure	Intervention group	Control group	Results
Worobey et al. (2016)	RCT 8 weeks	Intervention: 36 Control: 43	WST-Q, GAS	Wheelchair skills training program (WSTP) · Eight weekly 90-minute WSTP classes (6 regular, 2 make-up). · WSTP participants were asked to attend a target of six classes	· Education and interaction classes on aging, weight management and nutrition	· The WSTP group demonstrated improvement in the WST-Q advanced skills score, while no significant changes were observed in the total capacity or performance scores. · Participants who attended more sessions and those with lower baseline skills achieved higher GAS and WST-Q improvements. · Wheelchair skills training produced a significant increase in advanced wheelchair skill capacity ($p = 0.02$). · Goal achievement was high, with a mean score of 65.6%.
Kirby et al. (2016)	RCT 1 year	Intervention: 53 Control: 53	· WST 4.1 · CHART Participants' Perceptions	· Five one-on-one WSTP for 30-45 minutes · Indoors, community and advanced	· Five home-based sessions, about 45 minutes, that focused on health promotion for persons with SCI. · Topics included: strength, ROM, and weight relief for pressure ulcer prevention	· Participants in the WSTP group demonstrated improvements in both total and advanced-level wheelchair skills scores. · The CHART Mobility sub-score showed meaningful improvement following the training. · The program produced significant gains in overall wheelchair skills capacity, confidence, environmental performance, and CHART mobility scores, with p-values ranging from less than .001 to .004.

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Author	Design and duration	Sample size (n)	Type of outcome measure	Intervention group	Control group	Results
Pelletier et al. (2015)	RCT 16 weeks	Intervention: 12 Control: 11	· Peak oxygen consumption (VO2 peak) · Aerobic endurance test · Muscle strength testing	PAG · 2x per week for 16 weeks · 20 minutes of aerobic exercise at a moderate to vigorous intensity and three sets of 10 repetitions (at 50–70% 1 repetition maximum; 1RM)	· A weekly community exercise program. · No specific guidance or encouragement on the minimum exercise intensity associated with the PAG.	· The PAG group showed significant increases in peak aerobic capacity, absolute power output and submaximal power output. · Strength improved in the PAG group for the vertical bench press, seated row and rickshaw press exercises. · Participants in the PAG group demonstrated higher adherence to the exercise program compared to the control group. · Overall, the SCI PAG intervention produced significant improvements in aerobic capacity ($p = 0.004–0.01$), submaximal endurance ($p = 0.01$), and upper-body strength ($p < 0.05$), with markedly higher adherence than the control group ($p = 0.01$).
Totosy et al. (2015)	RCT 16 weeks	Intervention: 12 Control: 11	· Blood biomarker · Body composition: dual-energy x-ray absorptiometry · Arterial structure and function	· PAG training: 20 minutes of moderate-vigorous aerobic exercise and upper-body strengthening exercises · Participants attended supervised exercise training sessions 2x per week for 16 weeks for 60 minutes per session.	· Active control · Unsupervised existing physical activity	· Whole-body mass, whole-body fat, visceral adipose tissue, and carotid artery distensibility were maintained in the PAG group, whereas the control group showed deterioration. · Although the PAG program did not produce improvements in vascular function or metabolic biomarkers, it significantly prevented declines in whole-body mass, fat mass, visceral adiposity, and carotid arterial stiffness ($p = 0.03 – 0.05$), indicating that PAG is effective for maintaining rather than improving cardiometabolic health in individuals with SCI.

HIE: High intensity exercises; FES: Functional electrical stimulation; GAS: Goal attainment score; OM: Outcome measure; PAG: Physical Activity Guideline; RCT: Randomised controlled trial; SCI: Spinal cord injury; WSTP: Wheelchair Skills Training Program; WST-Q: Wheelchair Skills Test Questionnaire

(d) Control conditions

Control groups typically received education-based or unsupervised physical activity interventions. Worobey et al. (2016) provided health education on aging and nutrition, while Kirby et al. (2016) incorporated home-based sessions focused on strength and pressure-relief practices. Similarly, Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) assigned participants to general, unsupervised exercise without standardised intensity or frequency. Across all studies, these control conditions led to minimal improvements, emphasising that structured, community-based and supervised engagement was essential to achieve meaningful physical and functional outcomes.

PEDro Methodological Quality of Study

The methodological quality of the included RCTs was assessed using the PEDro scale, which was specifically designed for physiotherapy and rehabilitation research. The PEDro scale assessed core aspects, including random allocation, allocation concealment, baseline comparability, blinding, follow-up and statistical reporting. Given its strong validity and reliability within rehabilitation studies, PEDro was deemed sufficient and appropriate for this review. The methodological quality of the included RCTs was assessed using the PEDro scale, as shown in Table 4. Overall, scores ranged from 6 to 10, indicating moderate to high methodological quality. Studies on community-based programs generally demonstrated stronger methodological rigor compared with home-based interventions, particularly in allocation concealment and assessor blinding.

Home-Based Physical Activity Programs

The four RCTs evaluating home-based physical activity programs, such as Nightingale et al. (2018), Wouda et al. (2018), Nightingale et al. (2017) and Mulroy et al. (2011), achieved moderate methodological quality, with PEDro scores ranging from 6 to 8.

(a) Eligibility criteria and random allocation

All studies clearly described eligibility criteria and used random assignment, ensuring adequate internal validity. This methodological consistency supported the reliability of findings across heterogeneous SCI samples.

(b) Concealed allocation and baseline similarity

Concealed allocation was reported in Nightingale et al. (2018) and Mulroy et al. (2011), reducing potential selection bias. All studies confirmed baseline similarity between groups regarding demographic and clinical variables, strengthening comparability.

(c) Blinding

Due to the practical limitations of home-based exercise interventions, participant and therapist blinding was not feasible. However, Wouda et al. (2018) and Mulroy et al. (2011) incorporated assessor blinding, improving data objectivity.

(d) Outcome measures and intention-to-treat analysis

All studies employed validated and reliable instruments, such as VO_2peak, SF-36 and fatigue and strength measures, ensuring strong measurement validity. ITT analysis was inconsistently reported, which may have influenced the management of missing data or attrition bias.

(e) Between-group comparison and data reporting

All studies provided between-group comparisons and reported variability data (means, SD, CI), supporting transparent interpretation and reproducibility.

TABLE 4: Study quality assessments using the PEDro scale (n = 8).

	Eligibility Criteria	Random Subject Allocation	Concealed allocation	Baseline Group Similarity	Blinding of Subjects	Blinding of Therapists	Blinding of Assessors	Outcome Measures	Intention to Treat	Between-Group Comparison	Point and Variability Data	Overall Score (level of study methodo-logical quality)
Study Methodological Quality of Home-based Physical Activity												
Nightingale et al. (2018)	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	7 (Moderate)
Wouda et al. (2018)	Yes	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes	7 (Moderate)
Nightingale et al. (2017)	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	6 (Moderate)
Mulroy et al. (2011)	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	8 (Moderate)
Study Methodological Quality of Community-based Physical Activity												
Worobey et al. (2016)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	10 (High)
Kirby et al. (2016)	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	7 (Moderate)
Pelletier et al. (2015)	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	6 (Moderate)
Totosy de Zepetnek et al. (2015)	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	7 (Moderate)

PEDro: Physiotherapy Evidence Database

(f) Overall quality

PEDro scores of 6–8 indicated moderate methodological strength. The main limitations included a lack of participant blinding and incomplete ITT reporting, which were common challenges in physiotherapy and exercise-based interventions conducted in home environments.

Community-Based Physical Activity Programs

The four RCTs evaluating community-based physical activity programs, such as Worobey et al. (2016), Kirby et al. (2016), Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) showed moderate to high methodological quality, with scores ranging from 6 to 10.

(a) Eligibility Criteria and Random Allocation

All studies met the inclusion and randomisation criteria, ensuring robust participant selection and internal validity.

(b) Concealed Allocation and Baseline Similarity

Concealed allocation was applied in Worobey et al. (2016) and Kirby et al. (2016), limiting selection bias. Baseline group similarity was reported consistently across all studies, reinforcing valid between-group comparisons.

(c) Blinding

Blinding of participants and therapists was largely infeasible, though Worobey et al. (2016) implemented partial subject and assessor blinding. This study attained the highest methodological rating (score = 10), reflecting exemplary rigor in randomisation, outcome assessment and data reporting.

(d) Outcome measures and intention-to-treat analysis

All community-based trials used reliable and standardised outcome tools, including WST-Q, GAS, VO_2peak and vascular indices. ITT analysis was more frequently applied in this group than in home-based studies, enhancing analytical robustness.

(e) Between-group comparison and data reporting

All studies performed between-group analyses and consistently presented point and variability data, enabling detailed evaluation of treatment effects and facilitating inclusion in meta-analyses.

(f) Overall quality

Among the community-based trials, Worobey et al. (2016) demonstrated high methodological quality (score = 10), while others (Kirby et al. 2016; Pelletier et al. 2015; Totosy de Zepetnek et al. 2015) were rated as moderate quality (scores = 6–7). Collectively, these studies showed strong design and reporting integrity, with methodological limitations primarily confined to blinding challenges inherent in behavioural rehabilitation research.

DISCUSSION

This review synthesised evidence from RCTs evaluating HCPA programs for individuals with SCI. The findings demonstrate that structured exercise interventions, regardless of delivery mode, can produce meaningful improvements in physical capacity, functional performance, and overall fitness, with community-based and supervised formats yielding the most consistent and clinically significant effects.

Effects on Physical Capacity, Functional Performance and Fitness

Both home and community-based interventions were associated with measurable physiological and functional gains. Home-based programs by Nightingale et al. (2017, 2018), Wouda et al. (2018) and Mulroy et al. (2011) improved cardiorespiratory endurance (VO_2peak), muscle strength, and shoulder function, while reducing pain and fatigue levels. The use of accessible modalities such as arm-crank ergometry and resistance bands promoted feasible, individualised training that enhanced aerobic capacity without specialised equipment. Conversely, community-based programs by Worobey et al. (2016), Kirby et al. (2016), Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) showed stronger effects on functional independence, wheelchair mobility and upper-limb strength. Group wheelchair skills training and supervised resistance or aerobic sessions significantly improved WST-Q scores, GAS outcomes and CHART Mobility sub-scores. These gains translated into enhanced daily mobility, improved cardiometabolic health, and better QoL, highlighting the multidimensional benefits of exercise beyond physiological adaptation. Consistent with evidence from neurodegenerative populations, such as the exercise-based intervention for mild Alzheimer's disease reported by Azizan et al. (2023), HCPA may enhance mood, motivation and overall life satisfaction in persons with SCI dimensions that are often underrepresented in traditional rehabilitation metrics. Collectively, the results confirm that both intervention types may be effective, but the magnitude and durability of improvement tend to be higher in supervised, community-integrated contexts, where structured feedback, peer interaction and environmental support enhance engagement and training fidelity.

Comparison of Exercise Modalities

The resistance training employed by Mulroy et al. (2011) and Pelletier et al. (2015) produced significant gains in upper-limb strength, torque generation and pain reduction, while aerobic interventions in the studies by Nightingale et al. (2017) and Wouda et al. (2018) primarily improved cardiovascular fitness, endurance and fatigue management. Importantly, combined aerobic-resistance protocols demonstrated synergistic effects, improving both metabolic health and musculoskeletal performance. This dual approach enhances mitochondrial function, optimises glucose utilisation and reinforces musculoskeletal function, thereby addressing both strength and cardiorespiratory limitations simultaneously (Clemente-Suárez et al. 2024). Such integrative training paradigms are particularly crucial in SCI populations, where muscle weakness, reduced aerobic capacity and systemic deconditioning coexist (Harvey et al. 2023).

Optimal Dosage and Application of the FITT Framework

The FITT principles varied across interventions, yet certain patterns emerged. Programs delivering exercise 2–3 sessions per week, at moderate-to-vigorous intensity (60–80% VO_2peak or 50–70% 1-RM), for 30–60 minutes per session, over 8–16 weeks, were associated with the most substantial physiological and functional gains. For example, Pelletier et al. (2015) and Totosy de Zepetnek et al. (2015) demonstrated significant aerobic and muscular improvements following 16 weeks of twice-weekly Physical Activity Guideline (PAG) based training, while Nightingale et al. (2018) achieved comparable cardiovascular outcomes in just 6 weeks using high-adherence, moderate-intensity home sessions. The type of exercise, whether upper-limb ergometry, resistance training, or wheelchair skills, was secondary to consistency, progression and individualisation of the workload. These findings support existing SCI exercise guidelines recommending at least 20 minutes of moderate-intensity aerobic activity twice weekly, supplemented with strength training for major functioning muscle groups (Pelletier 2023). The results also suggest that programs integrating progressive overload and functional relevance (e.g., wheelchair propulsion tasks, upper-body transfers) yield superior translation to daily activity performance.

Comparison of Delivery Modes (Feasibility, Adherence, and Participant Satisfaction)

When comparing delivery modes, supervised and community-based formats consistently outperformed unsupervised or purely home-based interventions. Feasibility outcomes across studies show high retention and adherence rates (80%) in supervised community programs and moderate adherence in home-based formats. Participants frequently reported enhanced self-efficacy, reduced feelings of isolation and improved participation satisfaction, particularly when programs were group-based or incorporated peer mentorship (Wedege et al. 2024). These psychosocial and environmental advantages translated into high adherence and retention rates, sustained motivation, and meaningful improvements in functional capability and perceived health. In contrast, remote or home-based programs, while more accessible, faced greater variability in adherence and exercise intensity.

Although SCI individuals frequently encounter barriers such as transportation challenges, high adaptive equipment costs, limited facility accessibility and fluctuating motivation (Hisham et al. 2022b; Mat Rosly et al. 2018), community-based programs have been shown to mitigate these issues by offering peer support, structured scheduling and professional supervision (Koh & Mortenson 2024). At the same time, home-based programs address similar challenges through flexible scheduling, reduced travel demands and lower overall costs (Barria et al. 2025). A study by Nightingale et al. (2018) demonstrated that when participants received structured guidance and self-monitoring tools, remote home-based exercise could still yield meaningful health benefits.

Our findings are consistent with prior systematic reviews. Similar to Van der Scheer et al. (2021), home-based programs using functional or voluntary exercise improved cardiorespiratory fitness and muscle strength among individuals with SCI when sufficient intensity was achieved. Likewise, Vachova et al. (2024) demonstrated that behaviour-supported interventions education, coaching, and feedback, significantly increased physical activity participation. However, unlike these reviews, our synthesis focuses specifically on home and community-based programs, highlighting real-world feasibility and adherence. Variations in intervention delivery and participant context explain minor discrepancies, yet all evidence supports home-based physical activity as an effective, sustainable strategy for long-term SCI health management.

Therefore, emerging technological supports, including telemonitoring systems and virtual coaching platforms, represent a promising avenue to strengthen adherence, enhance continuity of care, and reduce social isolation among individuals with SCI (Brahmbhatt et al. 2022). These tools have the potential to bridge the gap between home- and community-based programs by providing real-time guidance, progress tracking, and opportunities for remote interaction with clinicians and peers.

Heterogeneity and Its Impact on Study Outcomes

Substantial heterogeneity was observed across studies in terms of participant characteristics, intervention dosage, and injury severity, which influenced the interpretation of outcomes. Sample sizes ranged from 21 to 106 participants, with smaller pilot trials demonstrating promising but less generalisable improvements in aerobic capacity, wheelchair skills and shoulder function, while larger studies confirmed functional gains and enhanced community mobility with greater confidence. Program duration varied from 6 to 52 weeks, and interventions ranged from moderate-intensity arm-ergometry to high-intensity training and multicomponent wheelchair-skills programs. Studies with longer and more frequent training sessions generally reported superior improvements in cardiovascular fitness, upper-limb strength, and participation outcomes, suggesting a dose-response relationship. Variation in neurological level and severity (from AIS A tetraplegia to AIS D paraplegia) also contributed to differential responsiveness; individuals with incomplete injuries tended to achieve greater functional gains, whereas those with complete injuries still demonstrated meaningful improvements in efficiency, self-efficacy and community participation when appropriately supported.

Although this heterogeneity complicates direct comparison and limits meta-analytic synthesis, it underscores the adaptability of HCPA models and highlights the importance of individualised prescriptions tailored to injury level, functional capacity, and environmental context.

The 'Rise and Falls' of Home and Community-Based Research Trends

Between 2010 and 2018, research on home- and community-based rehabilitation interventions experienced a notable surge, driven by increased recognition of health inequities among individuals with disabilities, advances in mobile health technology and policy initiatives emphasising decentralisation of care (Ahmed et al. 2025; Musselman et al. 2018; Kirby et al. 2016). This expansion reflected a paradigm shift toward patient-centered rehabilitation and the empowerment of individuals to self-manage long-term conditions within familiar environments. However, publication trends began to decline after approximately 2018 for home-based and 2016 for community-based interventions. This apparent reduction likely represents not a true loss of interest, but rather a conceptual evolution toward hybrid or digital rehabilitation models such as tele-supervised, web-enabled or app-integrated programs that no longer fall neatly under traditional categorical terms. The global pivot to telehealth during the COVID-19 era further accelerated this methodological transition (Mirbaha et al. 2023). Concurrently, persistent challenges in standardising intervention protocols, ensuring long-term adherence, and maintaining supervision fidelity in unsupervised or resource-limited settings may have tempered the expansion of conventional home- and community-based trials.

Limitations of the Study

This systematic review is subject to several limitations that should be acknowledged. The evidence base remains limited due to the small number of eligible RCTs (n = 8), which constrains the robustness and generalisability of the conclusions. Furthermore, the included studies demonstrated only moderate methodological quality based on PEDro assessments, indicating a potential risk of bias. The predominance of male participants across the trials also introduces a gender imbalance that may limit the applicability of the findings to female individuals with SCI. In addition, the lack of long-term follow-up data across most studies restricts insight into the sustained effectiveness of HCPA interventions. Finally, heterogeneity in intervention approaches and outcome measures precluded the conduct of a meta-analysis, thereby limiting the ability to synthesise and compare outcomes across studies quantitatively.

Future Research Directions

HCPA programs are feasible, safe and safety in functional performance and physiological health for individuals with SCI. Collectively, findings from related populations, including those with cognitive and mobility impairments (Azizan et al. 2023), further affirm that structured physical activity contributes to both physical and psychosocial resilience. These interventions have demonstrated meaningful gains in cardiorespiratory fitness, muscular strength, functional independence, and quality of life. Clinically, these findings support the implementation of HCPA models that prioritise safety screening, appropriate progression of exercise intensity, and ongoing monitoring to ensure safe and effective participation. Integrating digital technologies and tele-supervised platforms can further enhance accessibility, continuity of care, and long-term engagement, particularly for individuals facing mobility or geographic barriers. Ultimately, standardised, individualised and digitally supported HCPA programs may bridge the gap between institutional rehabilitation and lifelong community participation for individuals with SCI. There is also a likelihood of publication bias, considerable heterogeneity across interventions and important data gaps in community-based studies, all of which may reduce the completeness, representativeness and overall strength of the available evidence.

CONCLUSION

HCPA programs are feasible, safe and moderately effective in improving health and functional outcomes among SCI individuals. Collectively, findings from related populations, including those with cognitive and mobility impairments, further affirm that structured physical activity contributes to both physical and psychosocial resilience. These interventions have demonstrated meaningful gains in cardiorespiratory fitness, muscular strength, functional independence, and quality of life. Clinically, these findings support the implementation of HCPA models that prioritise safety screening, appropriate progression of exercise intensity and ongoing monitoring to ensure safe and effective participation. Integrating digital technologies and tele-supervised platforms can further enhance accessibility, continuity of care and long-term engagement, particularly for individuals facing mobility or geographic barriers. Ultimately, standardised, individualised and digitally supported HCPA programs may bridge the gap between institutional rehabilitation and lifelong community participation for individuals with SCI. Healthcare providers should integrate HCPA into long-term rehabilitation pathways, and policymakers should prioritise community resources, funding mechanisms and digital infrastructure to support scalable HCPA options for individuals with SCI.

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REFERENCES

Ahmed, M.M., Okesanya, O.J., Olaleke, N.O., Adigun, O.A., Adebayo, U.O., Oso, T.A., Eshun, G., Lucero-Prisno, D.E. 2025. Integrating digital health innovations to achieve universal health coverage: Promoting health outcomes and quality through global public health equity. *Healthcare* **13**(2): 1060. https://doi.org/10.3390/healthcare13091060

Azizan, A. 2024. Exercise and frailty in later life: A systematic review and bibliometric analysis of research themes and scientific collaborations. *Int J Popul Stud* **11**(1): 3282. https://doi.org/10.36922/ijps.3282

Azizan, A., Anum, A., Faisal, A., Karnadipa, T. 2023. The effects of exercise and reminiscence therapy on depression and quality of life among

the older adults with mild Alzheimer's disease. *J Adv Res Appl Sci Eng Technol* **29**(3): 185-97. https://doi.org/10.37934/araset.29.3.185197
Barria, P., Andrade, A., Yelincic, A., Córdova, B., Covarrubias-Escudero, F., Cifuentes, C., Appelgren-Gonzalez, J.P. 2025. Impact of a long-term home-based rehabilitation program on quality of life, balance, and autonomy in adults with disabilities. *J Funct Morphol Kinesiol* **10**(1): 24. https://doi.org/10.3390/jfmk10010024
Brahmbhatt, D.H., Ross, H.J., Moayedi, Y. 2022. Digital technology application for improved responses to health care challenges: Lessons learned from COVID-19. *Can J Cardiol* **38**(2): 279-91. https://doi.org/10.1016/j.cjca.2021.11.014
Budd, M.A., Gater, D.R., Channell, I. 2022. Psychosocial consequences of spinal cord injury: A narrative review. *J Pers Med* **12**(7): 1178. https://doi.org/10.3390/jpm12071178
Cashin, A.G., McAuley, J.H. 2020. Clinimetrics: physiotherapy evidence database (PEDro) scale. *J Physiother* **66**(1): 59. https://doi.org/10.1016/j.jphys.2019.08.005
Clemente-Suárez, V.J., Rubio-Zarapuz, A., Belinchón-de Miguel, P., Beltrán-Velasco, A.I., Martín-Rodríguez, A., Tornero-Aguilera, J.F. 2024. Impact of physical activity on cellular metabolism across neurological conditions: A narrative review. *Cells* **13**(12): 1940. https://doi.org/10.3390/cells13231940
Declerck, L., Stoquart, G., Lejeune, T., Vanderthommen, M., Kaux, J.F. 2021. Barriers to development and expansion of adaptive physical activity and sports for individuals with physical disability in sports clubs and centres. *Sci Sports* **36**(2): 120-7. https://doi.org/10.1016/j.scispo.2020.12.002
Di Giulio, F., Castellini, C., Palazzi, S., Tienforti, D., Antolini, F., Felzani, G., Baroni, M.G., Barbonetti, A. 2024. Correlates of metabolic syndrome in people with chronic spinal cord injury. *J Endocrinol Invest* **47**(8): 2097-105. https://doi.org/10.1007/s40618-023-02298-8
Ding, W., Hu, S., Wang, P., Kang, H., Peng, R., Dong, Y., Li, F. 2022. Spinal cord injury: the global incidence, prevalence, and disability from the global burden of disease study 2019. *Spine* **47**(21): 1532-40. https://doi.org/10.1097/BRS.0000000000004417
Froehlich-Grobe, K., Lee, J., Ochoa, C., Lopez, A, Sarker, E., Driver S., Shegog, R., Lin, S.J. 2022. Effectiveness and feasibility of the Workout on Wheels Internet Intervention (WOWii) for individuals with spinal cord injury: A randomized controlled trial. *Spinal Cord* **60**(10): 862-74. https://doi.org/10.1038/s41393-022-00787-w
Fryer, S., Caggiari, S., Major, D., Bader, D.L., Worsley, P.R. 2023. Continuous pressure monitoring of inpatient spinal cord injured patients: implications for pressure ulcer development. *Spinal Cord* **61**(2): 111-8. https://doi.org/10.1038/s41393-022-00841-7
Grossmann, F., Flueck, J.L., Perret, C., Meeusen, R., Roelands, B. 2021. The thermoregulatory and thermal responses of individuals with a spinal cord injury during exercise, acclimation and by using cooling strategies: A systematic review. *Front Physiol* **12**(1): 636997. https://doi.org/10.3389/fphys.2021.636997
Hadar-Frumer, M., Ten Napel, H., Yuste-Sánchez, M.J., Rodríguez-Costa, I. 2023. The International Classification of Functioning: Accuracy in aquatic activities among children with developmental delay. *Children (Basel)* **10**(6): 908. https://doi.org/10.3390/children10050908
Harvey, L.A., Glinsky, J.V., Chu, J., Herbert, R.D., Liu, H., Jan, S., Billot, L., Scivoletto, G., Spooren, A.I., Seelen, H.A., Ben, M., et al. 2023. Early and intensive motor training to enhance neurological recovery in spinal cord injury: Trial protocol. *Spinal Cord* **61**(6): 521-7. https://doi.org/10.1038/s41393-023-00908-z
Hisham, H., Justine, M., Hasnan, N., Manaf, H. 2022a. Effects of paraplegia fitness integrated training on physical function and exercise self-efficacy among individuals with spinal cord injury. *Ann Rehabil Med* **46**(1): 33-44. https://doi.org/10.5535/arm.21127
Hisham, H., Rosley, H., Manaf, H., Justine, M. 2022b. Barriers and facilitators to physical activity among individuals with spinal cord injury: A systematic review. *Malays J Med Health Sci* **18**(2): 46.
Hisham, H., Mohd Nordin, N.A., Aluwi, M.F. 2025. Perspective Chapter: Empowerment through movement: Enhancing psychosocial well-being in people with physical disabilities. In *Movement as Medicine - Harnessing Physical Activity for Holistic Health across the Lifespan. IntechOpen* **1**(1): 139-64. https://doi.org/10.5772/intechopen.1009108
Jeyathevan, G., Craven, C., Cameron, J.I., Jaglal, S.B. 2020. Facilitators and barriers to supporting people with spinal cord injury in the community: Caregiver and care recipient perspectives. *Disabil Rehabil* **42**(12): 1844-54. https://doi.org/10.1080/09638288.2018.1541102
Kirby, R.L., Mitchell, D., Sabharwal, S., McCranie, M., Nelson, A.L. 2016. Manual wheelchair skills training for community-dwelling veterans with spinal cord injury: A randomized controlled trial. *PLoS One* **11**(1): e0168330. https://doi.org/10.1371/journal.pone.0168330
Koh, P.P.W., Mortenson, W.B. 2024. Evaluating a pilot community-based self-management program

for adults with spinal cord injury. *J Spinal Cord Med* **47**(5): 881-92. https://doi.org/10.1080/10790268.2023.2220510

Lu, Y., Shang, Z., Zhang, W., Pang, M., Hu, X., Dai, Y., Shen, R., Wu, Y., Liu, C., Luo, T., Wang, X., Liu, B., Zhang, L., Rong, L. 2024. Global incidence and characteristics of spinal cord injury from 2000 to 2021: A systematic review and meta-analysis. *BMC Med* **22**(1): 285. https://doi.org/10.1186/s12916-024-03514-9

Mat Rosly, M., Halaki, M., Hasnan, N., Mat Rosly, H., Davis, G.M., Husain, R. 2018. Leisure time physical activity participation in individuals with spinal cord injury in Malaysia: Barriers to exercise. *Spinal Cord* **56**(9): 806-18. https://doi.org/10.1038/s41393-018-0068-0

Manaf, H., Shaid, A., Justine, M., Hisham, H., Hasnan, N., Mohd Asmawi, U.M., Mustapa, A. 2021. Barriers to physical activity among persons with physical disability in a teaching hospital. *Malays J Med Health Sci* **17**(2): 1-6.

Manaf, H., Tahir, I., Hisham, H., Justine, M., Hasnan, N. 2018. Return to work after spinal cord injury: A systematic review. *Adv Sci Lett* **24**(4): 2374-7. https://doi.org/10.1166/asl.2018.10957

Mirbaha, S., Morgan, A., Tang, A., Smith-Turchyn, J., Richardson, J. 2023. Models of telehealth service delivery in adults with spinal cord injuries: Scoping review. *JMIR Rehabil Assist Technol* **10**(1): e41186. https://doi.org/10.2196/41186

Mulroy, S.J., Thompson, L., Kemp, B., Hatchett, P.P., Newsam, C.J., Lupold, D.G., Haubert, L.L., Eberly, V., Ge, T.T., Azen, S.P., Winstein, C.J., Gordon, J.; Physical Therapy Clinical Research Network (PTClinResNet) 2011. Strengthening and optimal movements for painful shoulders in chronic spinal cord injury: A randomized controlled trial. *Phys Ther* **91**(3): 305-24. https://doi.org/10.2522/ptj.20100182

Musselman, K.E., Shah, M., Zariffa, J. 2018. Rehabilitation technologies for spinal cord injury: Translational potential. *J Neuroeng Rehabil* **15**(1): 40. https://doi.org/10.1186/s12984-018-0386-7

Nightingale, T.E., Rouse, P.C., Walhin, J.P., Thompson, D., Bilzon, J.L.J. 2018. Home-based exercise enhances health-related quality of life in spinal cord injury: A randomized controlled trial. *Arch Phys Med Rehabil* **99**(11): 1998-2006. https://doi.org/10.1016/j.apmr.2018.05.008

Nightingale, T.E., Walhin, J.P., Thompson, D., Bilzon, J.L. 2017. Impact of exercise on cardiometabolic component risks in spinal cord–injured humans. *Med Sci Sports Exerc* **49**(12): 2469-76. https://doi.org/10.1249/MSS.0000000000001390

Pelletier, C.A., Totosy de Zepetnek, J.O., MacDonald, M.J., Hicks, A.L. 2015. A 16-week randomized controlled trial evaluating the SCI physical activity guidelines. *Spinal Cord* **53**(5): 363-7. https://doi.org/10.1038/sc.2014.167

Pelletier, C. 2023. Exercise prescription for persons with spinal cord injury: A review of physiological considerations and evidence-based guidelines. *Appl Physiol Nutr Metab* **48**(8): 882-95. https://doi.org/10.1139/apnm-2023-0227

Peters, J., Abou, L., Rice, L.A., Dandeneau, K., Alluri, A., Salvador, A.F., Rice, I. 2021. Effectiveness of vigorous training on cardiorespiratory fitness in spinal cord injury: A systematic review. *Spinal Cord* **59**(9): 1035-44. https://doi.org/10.1038/s41393-021-00669-7

Raguindin, P.F., Fränkl, G., Itodo, O.A., Bertolo, A., Zeh, R.M., Capossela, S., Minder, B., Stoyanov, J., Stucki, G., Franco, O.H., Muka, T., Glisic, M. 2021. Neurological level of spinal cord injury and cardiovascular risk factors: A meta-analysis. *Spinal Cord* **59**(10): 1135-45. https://doi.org/10.1038/s41393-021-00678-6

Rayes, R., Ball, C., Lee, K., White, C. 2022. Adaptive sports in spinal cord injury: A systematic review. *Curr Phys Med Rehabil Rep* **10**(4): 232-47. https://doi.org/10.1007/s40141-022-00358-3

Sivaramakrishnan, H., Phoenix, C., Quested, E., Thogersen-Ntoumani, C., Gucciardi, D.F., Cheval, B., Ntoumanis, N. 2023. More than just a walk in the park: A multi-stakeholder qualitative exploration of community-based walking sport programmes for middle-aged and older adults. *Qual Res Sport Exerc Health* **15**(5): 772-88. https://doi.org/10.1080/2159676X.2023.2197450

Totosy de Zepetnek, J.O., Pelletier, C.A., Hicks, A.L., MacDonald, M.J. 2015. Following the SCI physical activity guidelines for 16 weeks does not improve vascular health: A randomized controlled trial. *Arch Phys Med Rehabil* **96**(8): 1566-75. https://doi.org/10.1016/j.apmr.2015.05.019

van der Scheer, J.W., Goosey-Tolfrey, V.L., Valentino, S.E., Davis, G.M., Ho, C.H. 2021. Functional electrical stimulation cycling after spinal cord injury: A systematic review. *J Neuroeng Rehabil* **18**(1): 99. https://doi.org/10.1186/s12984-021-00882-8

Vachova, P., Fini, N.A., Wittwer, J., Peiris, C.L. 2024. Effectiveness of interventions to increase physical activity in adults with spinal cord injury: A systematic review. *Disabil Rehabil* **46**(13): 5158-68. https://doi.org/10.1080/09638288.2023.2291550

Wedege, P., Mæland, S., Abrahamsen, F.E., Divanoglou, A. 2024. Peer-mentorship activity programmes for individuals with brain or spinal cord injuries: A mixed-methods review. *Disabil Rehabil* **46**(15): 5442-57. https://doi.org/10.1080/09638288.2024.2310185

World Health Organisation. 2001. International Classification of Functioning, Disability and Health (ICF). Geneva: World Health Organization. https://www.who.int/publications/i/item/9241545429 [Accessed on 26 October 2025]

Worobey, L.A., Kirby, R.L., Heinemann, A.W., Krobot, E.A., Dyson-Hudson, T.A., Cowan, R.E., Pedersen, J.P., Shea, M., Boninger, M.L. 2016. Effectiveness of group wheelchair skills training: A randomized controlled trial. *Arch Phys Med Rehabil* **97**(10): 1777-84. https://doi.org/10.1016/j.apmr.2016.04.006

Wouda, M.F., Lundgaard, E., Becker, F., Strøm, V. 2018. Effects of moderate- and high-intensity aerobic training in incomplete spinal cord injury: A randomized controlled trial. *Spinal Cord* **56**(10): 955-63. https://doi.org/10.1038/s41393-018-0140-9

Yokota, K., Sakai, H., Kawano, O., Morishita, Y., Masuda, M., Hayashi, T., Maeda, T. 2024. Changing trends in traumatic spinal cord injury in an aging society: Epidemiology of 1152 cases over 15 years from a single center in Japan. *PLoS One* **19**(3): e0298836. https://doi.org/10.1371/journal.pone.0298836

Zhou, W., Zhang, X., Lyu, X. 2025. Monitoring utilisation patterns of home- and community-based services for healthy ageing: A cross-sectional study. *BMC Geriatr* **25**(1): 1-12. https://doi.org/10.1186/s12877-025-05918-5