

SCORE

SPINAL CORD INJURY REHABILITATION EVIDENCE

Physical Activity

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Key Points

Physical Activity: Effects on Muscle Morphology, Strength and Endurance in Persons with SCI

Circuit resistance training, body-weight support treadmill training and functional electrical stimulation (upper and lower limbs) may be effective in increasing muscle strength and reducing atrophy, with the latter two more appropriate for those with great muscle impairment.

Physical Activity and Functional Improvement Including Activities of Daily Living

Generally physical activity programming may be useful in improving functional outcomes such as performance of ADLs, but specific exercise and program parameters are not readily available.

Physical Activity and Subjective Well-Being

Exercise is an effective strategy for improving at least two aspects of subjective well-being - depression and quality of life.

Physical Activity and Secondary Conditions

There is limited evidence that BWSTT can improve indicators of cardiovascular health in individuals with complete and incomplete SCI.

Persons with tetraplegia and paraplegia can improve their cardiovascular fitness and physical work capacity through moderate intensities of aerobic exercise or resistance training, although optimal program parameters are not known.

Interventions that involve FES training a minimum of 3 days per week for 2 months can improve muscular endurance, oxidative metabolism, exercise tolerance, and cardiovascular fitness.

Aerobic and FES exercise training may lead to clinically significant improvements in glucose homeostasis in persons with SCI. Preliminary evidence indicates that a minimum of 30 min of moderate intensity training 3 days per week is required to achieve and/or maintain the benefits from exercise training.

Aerobic and FES exercise training may lead to improvements in lipid lipoprotein profiles that are clinically relevant for the at-risk SCI population. The optimal training program for changes in lipid lipoprotein profiles remains to be determined. However, a minimal aerobic exercise intensity of 70% of heart rate reserve on most days of the week appears to be a good general recommendation for improving lipid lipoprotein profiles in persons with SCI.

Physical Activity and Respiratory Complications

For exercise training to improve respiratory function the training intensity must be relatively high (70-80% of maximum heart rate) performed three times per week for six weeks. Ideal training regimes have not been identified.

There is limited evidence that inspiratory muscle training improves respiratory muscle strength or endurance in people with SCI.

Physical Activity and Bone Health

Short term (6 weeks) therapeutic ultrasound is not effective for preventing bone loss after SCI.

FES-cycling does not improve or maintain bone at the tibial midshaft in the acute phase but may increase/maintain lower extremity BMD the greater the time since injury.

Electrical stimulation can maintain or increase BMD over the stimulated areas.

Six months of FES cycle ergometry may increase lower extremity BMD over areas stimulated.

There is inconclusive evidence for Reciprocating Gait Orthosis, long leg braces, passive standing or self-reported physical activity as a treatment for low bone mass.

Physical Activity and Pain

Regular exercise reduces post-SCI pain.

Shoulder exercise protocol reduces post-SCI shoulder pain intensity.

Physical Activity and Spasticity

Hippotherapy may result in short-term reductions in spasticity.

A combination of neural facilitation techniques and Baclofen may reduce spasticity.

Rhythmic passive movements may produce short-term reductions in spasticity.

Prolonged standing or other methods of producing muscle stretch may result in reduced spasticity.

Active exercise interventions such as hydrotherapy and FES -assisted walking may produce short-term reductions in spasticity.

Physical Activity and Periodic Leg Movements

Aerobic exercise is effective in reducing night-time periodic limb movements in persons with complete paraplegia.

Physical Activity Participation Levels in SCI

There is tremendous variability in the amount of physical activity performed by people living with SCI. A large segment of the population does not engage in any leisure-time physical activity whatsoever.

Barriers to Physical Activity Participation in the SCI Population

Individuals with SCI encounter numerous impediments to physical activity participation including intrapersonal, systemic, and expertise barriers. Interventions are needed to help people with SCI manage these barriers.

Effectiveness of Interventions to Increase Physical Activity Participation in SCI

Behavioural interventions promoting physical activity in the SCI population can lead to increased levels of physical activity participation.

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Physical Activity and Spinal Cord Injury

1 Introduction

Many authors have noted the importance of participation in physical activity and exercise programming for persons with spinal cord injury (SCI) and several of these have provided reviews of the various purported benefits that may occur with regular and appropriate physical activity (Cowell et al. 1986; Washburn & Fignoni 1999; Jacobs & Nash 2001; Nash 2005; Devillard et al. 2007; Fernhall et al. 2008). Despite this assertion and the relative plethora of studies cited within these reviews, especially in some areas (e.g., cardiovascular fitness), there is much that remains to be established about the relationship of exercise and physical activity to the health and well-being of persons with SCI. It has been noted that the majority of physical activity studies are often lower quality with few randomized controlled trials (RCTs) (Valent et al. 2007; Fernhall et al. 2008), which is not surprising as exercise studies are challenging to conduct in and of themselves and this is compounded by multiple further challenges that are presented within the SCI population (Ginis & Hicks, 2005). Little is known about the details of what exercise modality might be best suited for individuals with SCI relative to their varying physical levels of function. Specific information about frequency, intensity and duration is typically lacking. In general, there is a dearth of evidence-based information on which to provide guidance for the promotion and prescription of exercise, especially for the various subsets of individuals that comprise this population (Ginis & Hicks 2007; Myslinski 2005).

The present chapter aims to describe the level of evidence that exists for physical activity and its effect on various aspects of health and wellness for persons with SCI. In particular, we review the evidence that exists for the effectiveness of physical activity on enhancing strength, muscle function, rehabilitation recovery (i.e., functional outcomes) and subjective well-being (including depression and quality of life) as well as the relationship of physical activity to the prevention and minimization of various secondary complications and other health conditions associated with SCI. Following this, we examine the studies that assess the rates of physical activity participation and identify barriers to participation noted in the literature. Finally, we describe the level of evidence associated with interventions targeted at persons with SCI designed to enhance participation in physical activity.

2 Effects of Physical Activity in Persons with SCI

SCI impacts many body systems both immediately and in the long-term as noted in numerous reviews (Bauman et al. 1999; Shields 2002; Nash 2005). In particular, Nash (2005) and Jacobs and Nash (2004) point to physical deconditioning across the musculoskeletal system (i.e., bone, muscle and joint) and alterations in both cardiac and peripheral vascular structure and functioning in persons with SCI. These issues, when combined with continued inactivity, result in seemingly inevitable body system decline and are linked to the increased incidence of various secondary complications and other health conditions associated with SCI such as cardiovascular disease, respiratory complications, osteoporosis, pain, spasticity and diabetes. Evidence for routine physical activity has been noted as an important factor in maintaining health and wellness and preventing many of these conditions in the able-bodied population and in those with chronic disease such as arthritis (US Department of Health and Human Services 1996; Warburton et al. 2006; Kruk 2007). However, the evidence linking health and physical activity in persons with SCI or similar conditions is far from established, despite the importance placed on physical activity by clinicians, consumers and researchers alike in optimizing recovery and maintaining health (Rimmer 1999; Anderson 2004; Fernhall et al. 2008).

In reviewing the literature associated with various physical activity and exercise interventions in SCI, it was apparent that the vast majority of studies examine physiological parameters (e.g., VO_2 , cardiovascular responses to exercise) that would be characterized as relating to body function and structure within the framework of the International Classification of Functioning, Disability and Health (ICF). We do not report here the numerous studies that address these physiologic outcome measures other than to note the various conclusions made surrounding specific risk factors associated with the development of cardiovascular disease or other health conditions. There is a relative dearth of studies examining the effect of physical activity interventions on functional outcomes, especially those that might be characterized as measures of activity or participation (as per the ICF). This suggests a target for future research in elucidating either the functional consequences or societal participation benefits associated with physical activity interventions for persons with SCI.

It should be noted that while one of the aims of this chapter is to bring the information about physical activity and SCI into one place, most of these topic areas comprise individual chapters with SCIRE. Therefore, when there may be substantial duplication with an existing SCIRE chapter we have selected to simply reference the existing chapters that contain information about physical activity interventions and to also bring forward the conclusions (evidence statements and bottom-line conclusions) from these chapters so the reader will gain a sense of the degree of evidence across these various conditions. The reader is encouraged to examine the referenced chapter for surrounding discussion and more information concerning the various studies and details about the specific interventions comprising the evidence. Of note, many of the therapies associated with upper limb or lower limb management involve therapeutic exercise programming (often associated with physical or occupational therapy) and for these we simply refer the reader to SCIRE Chapters: Upper Limb Rehabilitation Following Spinal Cord Injury (Connolly et al. 2010) and Lower Limb Rehabilitation Following Spinal Cord Injury (Lam et al. 2010) respectively. This means that the conclusions related to specific rehabilitation interventions (e.g., Body weight supported treadmill training, FES upper and lower limb applications) may not be comprehensive within the present chapter, but should be augmented by those from the noted chapters.

The following section describes the evidence for physical activity as an intervention directed towards persons with SCI in enhancing strength, muscle function, rehabilitation recovery (i.e., functional outcomes) and subjective well-being (including depression and quality of life) as well as in preventing or minimizing common secondary conditions typically encountered following SCI. These include the role of physical activity in maintaining or enhancing cardiovascular health and bone health as well as preventing or mitigating disability associated with respiratory complications, pain, spasticity and periodic leg movements.

2.1 Physical Activity: Effects on Muscle Morphology, Strength and Endurance in Persons with SCI

Even though the most visible aspect of SCI involves impaired muscle function ranging from slight weakness to complete paralysis, there is far more research addressing aerobic training than pure resistance training for enhancing strength, endurance and other aspects of muscle function (Jacobs and Nash 2004). The effects of aerobic exercise on aerobic capacity will be summarised in a subsequent section that is focused on cardiovascular health. The present section describes the effects of various forms of exercise (i.e., not only pure resistance training but also those that incorporate the more frequently implemented endurance training as well) and the various adaptations that result in increased muscle mass. These adaptations are characterized as those pertaining to muscle morphology or muscle function. Muscle

morphological changes in response to appropriately configured physical activity interventions are reflected in such outcomes as overall changes to muscle cross-sectional area (i.e, direct or indirect measures such as limb circumference) or in changes to individual muscle fibres as reflected by changes in individual muscle fibre size or fibre type. Changes in muscle function are often assessed by direct measurements of muscle strength or power output or might be reflected in muscular endurance (i.e., exercise capacity changes) such as that seen in the ability to manage greater loads over a longer period of time during a progressive exercise program.

Table 1: Physical Activity and Adaptations to Muscle Morphology and Strength

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|--|
| Muscle Morphology | | |
| Carvalho et al. 2008 Brazil Downs & Black score=21 Prospective Controlled Trial N=15 | <p>Population: Traumatic SCI: Mean age: 31.95±8.01 yrs; Gender: 15 males; Mean body mass: 63.52±9.41 kg; Mean height: 176.28±5.28 cm; Mean time post-injury: 66.43±48.23 mo</p> <p>Treatment: Gait group (n=8): Treadmill gait training at 0.5 km/h (increased according to individual's capacity) with partial body weight support (BWS) and neuromuscular electrical stimulation (NMES) delivered by a custom built four-channel stimulator (200V at 25Hz with 300ms duration). Training was performed over 6 mo, 2d/wk, for 20 min each session. Control group (n=7) : individuals performed only conventional physiotherapy 2d/wk for 6 mo without using NMES.</p> <p>Outcome Measures: MRI of bilateral thighs was performed in all participants, to determine the average cross sectional area (CSA) of quadriceps and mean value of gray scale. Outcomes were obtained at baseline and at the end of treatment (6 mo).</p> | <ol style="list-style-type: none"> 1. At moment of inclusion in this study, the average CSA values for the gait group and control group did not differ significantly. 2. After 6 months, a significant increase of 15% quadriceps CSA occurred in the gait group. 3. A 7.7% increase in gray scale value was also observed but was not statistically significant. 4. In the control group, no significant change in CSA or gray scale value was found after 6 months, but there was a noteworthy decrease in gray scale value of 11.4% |
| Scremin et al. 1999 USA Downs & Black score=21 Pre-Post N=13 | <p>Population: Age (range): 24-46 yrs; Gender: 13 males; Level of injury (range): C5-L1; Severity of Injury: ASIA A (100%); Time post-injury (range): 2-19 yrs</p> <p>Treatment: 3 phase, FES induced, ergometry exercise program. Phase 1: quadriceps strengthening; Phase 2: progressive sequential stimulation to achieve a rhythmic pedaling motion; Phase 3: FES induced cycling for 30 min</p> <p>Outcome Measures: Muscle cross-sectional area and proportion of muscle and adipose tissue measured at baseline, at the first follow-up (mean 65.4 wks), and at second follow-up (mean 98.2 wks)</p> | <ol style="list-style-type: none"> 1. The cross sectional area of the rectus femoris increased by 31% (p<0.001), the sartorius increased by 22% (p<0.025), the adductor magnus-hamstrings increased by 26% (p<0.001), the vastus lateralis increased by 39% (p=0.001), and the vastus medialis-intermedius increased by 31% (p=0.025). 2. The cross-sectional area of the adductor longus and gracilis muscles did not change. The ratio of muscle to adipose tissue increased significantly in thighs and calves. |
| Sabatier et al. 2006 USA Downs & Black score=21 | <p>Population: Mean age: 35.6 yrs; Gender: 5 males; Severity of injury: AIS A (100%); Mean time post-injury: 13.47±6.5 yrs</p> | <ol style="list-style-type: none"> 1. Training resulted in significant increases in weight lifted and muscle mass and a 60% reduction in muscle fatigue (p=0.001). |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| Pre-Post N=5 | <p>Treatment: Patients underwent 18 wks of home-based neuromuscular electrical stimulation (NMES) resistance training on the quadriceps muscle group 2d/wk with 4 sets of 10 dynamic knee extensions against resistance while in a seated position</p> <p>Outcome Measures: Femoral arterial diameter resting blood flow, blood velocity, and neuromuscular fatigue. All measurements were made before training and after 8, 12, and 18 wks of training.</p> | <ol style="list-style-type: none"> 2. Femoral arterial diameter did not increase ($p=0.70$). Resting, reactive hyperemic, and exercise blood flow did not appear to change with training. 3. Quadriceps femoris muscle CSA was increased in both thighs after 18 weeks. 4. The mean QF CSA of the right thigh was significantly increased from 32.6 to 44.0 cm² ($p<0.05$), and the left QF was increased from 34.6 to 47.9 cm² ($p<0.05$) which is a 35% and 39% increase in CSA respectively. |
| Kern et al. 2010 Austria Downs & Black score=19 Pre-Post N=25 | <p>Population: Complete conus cauda syndrome: Age (range): 20-55 yrs; Gender: 20 males, 5 females; Time post-injury (range): 0.7-8.7 yrs;</p> <p>Treatment: Muscles of patients were electrically stimulated at home by large surface area electrodes and a custom designed stimulator.</p> <p>Outcome Measures: Force induced by electrical stimulation, isometric knee extension torque, force measurements, area and density of quadriceps muscle and hamstring, tissue type distribution recorded before, at 1 yr, and after the 2 yrs of training</p> | <ol style="list-style-type: none"> 1. Similar increase in muscle excitability and contractility in both legs. 2. Improved feasibility to elicit tetanic contractions with about ten times improvement. 3. Myofiber size increased by 94% after 2 years of FES. 4. Functional class improved to a level 4 for 20% of the subjects. 5. After 2 years of home-based FES, the degenerative phase of LMN denervation was delayed or reverted. |
| Griffin et al. 2009 USA Downs & Black score=19 Pre-Post N=18 | <p>Population: Traumatic SCI: Mean age: 40±2.4 yrs; Gender: 13 males, 5 females; Time post-injury: 11±3.1 yrs</p> <p>Treatment: FES cycling performed on an Ergys2 automated recumbent bicycle 2–3 d/wk for 10 wks</p> <p>Outcome Measures: Total body mass, lean muscle mass</p> | <ol style="list-style-type: none"> 1. Training week had a statistically significant effect on the ride time without manually assisted pedaling. Ride times during training weeks 5–10 were statistically greater than during week 1. 2. Total body mass (3%) and lean muscle mass (4%) significantly increased, while, there was no significant difference in bone or adipose tissue following the 10 weeks of training 3. |
| Carvalho et al. 2009 Brazil Downs & Black score=19 Cohort N=7 | <p>Population: Traumatic SCI: Mean age: 32.8±3.5 yrs; Gender: 7 males; Mean body mass: 65.5±10.6 kg; Mean height: 176.8±8.4 cm; Mean time post-injury: 55.3± 10.6 mo</p> <p>Treatment: Individuals performed conventional physiotherapy, 2d/ wk without using NMES for 6 mo. After 6 mo, the CG was provided an additional 6 mo of gait training without NMES.</p> <p>Outcome Measures: MRI of bilateral thighs was performed on all participants, to determine the average cross sectional area (CSA) of quadriceps. Outcomes were measured 6 months post intervention.</p> | <ol style="list-style-type: none"> 1. 1 year post Carvalho et al. (2008) intervention no significant changes were observed in the quadriceps CSA in individuals receiving conventional physiotherapy. |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---|
| Giangregorio et al. 2006 Canada Downs & Black score=18 Pre-Post N=14 | <p>Population: Chronic Incomplete SCI: Mean age: 29 yrs; Gender: 11 males, 3 females; Level of injury: Tetraplegia (11), Paraplegia (3); Severity of injury: ASIA C (86%); ASIA B (14%); Mean time post-injury: 7.7 yrs</p> <p>Treatment: Body weight supported treadmill training (BWSTT) program - 144 sessions, 3 d/wk.</p> <p>Outcome Measures: Lean body mass; Muscle cross sectional area (CSAs).</p> | <ol style="list-style-type: none"> 1. BWSTT training ↑ whole body lean mass ($p<0.003$). 2. ↑ muscle CSAs in the thigh (4.9%) and lower leg (8.2%). |
| Willoughby et al. 2000 USA Downs & Black score=17 Pre-Post N=10 | <p>Population: Age (range): 16-50 yrs; Gender: 5 males, 3 females; Level of injury (range): C4-T12; Severity of injury: AISA A and C; Time post- injury(range):1-9.4yrs</p> <p>Treatment: 12 wk exercise program using the Psycle ergometer. Training 2 d/wk at 75% of each subject's maximum heart rate.</p> <p>Outcome Measures: Thigh girth, body weight, and body mass index measured before and after training.</p> | <ol style="list-style-type: none"> 1. mRNA expression had a significant increase in expression of MHC types IIa and Iix, and significant decreases in the expression for UBI, E2, and 20S. 2. The overall mean decrease for body weight and BMI from pre-training to post-training decreased for all eight subjects $1.82\pm4.4\%$ and $1.40\pm1.3\%$, respectively. 3. There was also an increase of 63.08%, 49.47%, and 61.39% that were significantly different for α-actin ($t(7)=2.61$ ($p=0.0413$), MHC type II a ($t(7)=3.04$ ($p=0.0188$), and MHC type II x ($t(7)=2.51$ ($p=0.0405$) respectively. |
| Heesterbeek et al. 2005 The Netherlands Downs & Black score=16 Pre-post N=10 | <p>Population: Chronic Paraplegia; Mean age: 39.3 yrs; Gender: 9 males, 1 female; Severity of injury: ASIA A (90%), ASIA C (10%); Mean time post-injury: 10.5 yrs</p> <p>Treatment: Exercise program – 4 wks, 8-12 total sessions. Each session consisted of a 5min warm-up, 30min hybrid (voluntary arm and FES-assisted leg) cycling & a 5min cool-down.</p> <p>Outcome Measures: Leg Volume; Graded Hybrid Exercise Test (GHT) - peak power output (PO_{peak}); Power of the legs (defined by delta power); all @ baseline & 4 wks.</p> | <ol style="list-style-type: none"> 1. Leg Volume: <ul style="list-style-type: none"> • Upper left leg: 8.3% ↑ ($p=0.018$) • Upper right leg: 8.5% ↑ ($p=0.047$) • Lower legs did not change. 2. PO_{peak}: ↑ 9.3% ($p=0.015$). 3. Power of legs: did not change |
| Chilibeck et al. 1999 Canada Downs & Black score=14 Pre-post N=6 | <p>Population: Chronic SCI: Age (range): 31-50 yrs Gender: 5 males, 1 female;; Time post-injury (range): 3-25 yrs</p> <p>Treatment: FES training with a leg cycle ergometer- 30 min, 3 d/wk for 8 wks</p> <p>Outcome Measures: Work rate, duration & total work output/exercise per session; Muscle fibre composition & area; Capillarization.</p> | <ol style="list-style-type: none"> 1. Mean fibre area: ↑ 23% after training ($p<0.05$) 2. Capillarization: capillary-to-fibre ratio ↑ 39% ($p<0.05$) & capillaries contacted with each fibre ↑ 29% ($p<0.05$). 3. Mean work rate: ↑ from 0 to 5.1 watts ($p<0.05$) from baseline to 8 wks. 4. Mean duration: continuously pedal without assistance ↑ from 4.3 min to 21.2 ± 5.6 min after training ($p<0.05$). 5. Mean total work output: ↑ from 0 to 9.2 KJ at 8 wks ($p<0.05$). |
| | Population: Chronic complete | 1. Paralysed vastus lateralis muscle |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| Crameri et al. 2002 Denmark Downs & Black score=14 Pre-post N=6 | paraplegia: Age (range): 28-43 yrs; Gender: 5 males, 1 female; Time post-injury (range): 8-36 yrs Treatment: FES leg cycle ergometry training- 30min/d, 3d/wk, for 10 wks Outcome Measures: Incremental exercise leg test to muscle fatigue (total work output); Histological assessment; Myosin heavy chain (MHC); Citrate synthase and hexokinase. | was altered with ↑ type IIA fibres, ↓ type IIX fibres ↓ MHC IIX and ↑ MHC IIA (p<0.05). 2. Total mean fibre cross-sectional area ↑ 129%, ↑ cross-sectional area of type IIA and IIX fibres (p<0.05). 3. Number of capillaries surrounding each fibre ↑ (p<0.05). 4. Citrate synthase and hexokinase activity ↑ (p<0.05). 5. Total work performed: ↑ after training (p<0.05) |
| Mohr et al. 1997 Denmark Downs & Black score=14 Pre-post N=10 | Population: Chronic Complete SCI: Age range: 27-45 yrs; Gender: 8 males, 2 females; Level of injury: Tetraplegia (6), Paraplegia (4); Time post-injury (range): 3-23 yrs Treatment: 1 yr exercise training using an FES cycle ergometer (30 min/d, 3 d/wk) Outcome Measures: Total work output; Muscle properties; @ baseline & 1 yr | 1. 12% ↑ in thigh muscle mass over 1 yr. 2. Muscle atrophy found @ baseline partially improved by 1 yr. 3. 4 fold ↑ in total work output. |
| Sloan et al. 1994 Australia Downs & Black score=14 Pre-post Initial N=12; Final N=9 | Population: Age range: 15-54 yrs; Gender: 7 males, 5 females; Severity of injury: complete (1), incomplete (11); Time post-injury (range): 2 -138 mo Treatment: Electrical stimulation induced cycling programme: 3d/wk for 3 mo, all programmes were individualized & gradually progressed to 30 min each. Outcome Measures: Quadriceps muscle area & Thigh muscle area – cross sectional analysis (CSA); Neurological muscle charts; @ baseline & 3 mo | 1. Muscle size: • ↑ Quadriceps CSA (p<0.05) • ↑ Total thigh CSA (p<0.05) 2. Muscle strength: • ↑ Voluntary isometric strength (p<0.05) • ↑ Stimulated isometric strength (p<0.05) ↑ Stimulated quadriceps endurance (p<0.05) • ↑ Quadriceps & biceps femoris grading (p<0.05). 3. Cycling improvement: • 9/9 ↑ cycling time by a mean of 11.7 min • 8/9 ↑ cycling load by a mean of 30N. • Speed=constant |
| Giangregorio et al. 2005 Canada Downs & Black score=13 Pre-post N=5 | Population: Tetraplegia; Age range: 19-40 yrs; Gender: 2 males, 3 females; Severity of injury: ASIA B (4), ASIA C (1); Time post-injury (range): 66-170 d Treatment: Body-weight supported treadmill training (BWSTT). Initial session started at 5min, ↑ gradually to 10-15min in all but 1 participant during 2d/wk training over a period of 6-8 mo Outcome measures: Muscle cross-sectional area (CSA) done pre & post treatment; Average adherence. | 1. ↑ muscle CSAs were seen in all patients. 2. Total body lean mass and fat mass ↑. 3. Partial reversal of muscle atrophy was seen. 4. Average adherence = 78%. |
| Crameri et al. 2004 Denmark Downs & Black score=22 | Population: Chronic complete paraplegia; Age range: 26-54 yrs; Time post-injury (range): 3-21 yrs Treatment: FES training 45 min/d, 3 d/wk, for 10 wks. One leg: dynamic cycle | 1. The isometric-trained leg showed significantly larger mean improvements force, type 1 fibres, fibre cross-sectional area, capillary-to-fibre ratio, citrate synthase activity |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|--|
| Prospective controlled trial N=6 | ergometry involving bilateral quadriceps and hamstring stimulation; Contralateral leg: isometric contractions. Outcome Measures: Muscle biopsies; Capillary-to-fibre ratio; Muscle proteins; Oxygenation. | & relative oxygenation after static training, in comparison to baseline & the dynamically trained leg. 2. These changes reflect the importance of load in the amount of adaptation to FES. |
| Hjeltne et al. 1997 Norway Downs & Black score=12 Pre-post N=5 | Population: Chronic Complete Tetraplegia; Mean age: 35 yrs; Gender: 5 males; Mean time post-injury: 10.2 yrs Treatment: 8 wks of FES leg cycling, 7d/wk Outcome Measures: Cross sectional area (CSA) of multiple muscles. | 1. 21.3% ↑ from 267cm ² to 324cm ² in muscle cross-sectional area for hamstrings, quadriceps, gluteus maximus & gluteus medius muscles (p<0.05). |
| Mahoney et al. 2005 USA Downs & Black score=11 Pre-post N=10 | Population: Chronic SCI; Mean age: 35.6 yrs; Gender: 5 males, 5 females; Mean time post-injury: 13.4 yrs Treatment: Residence-based, resistance exercise training (RET) for thighs for 12 wks, 2d/wk for 4 sets of 10 unilateral, dynamic knee extensions. RET induced extensions via neuromuscular electric stimulation. Outcome Measures: Muscle cross sectional area (CSA) - quadriceps femoris; @ baseline & 12 wks. | 1. Muscle CSA: 35% ↑ in right quadriceps femoris (32.6cm ² @ baseline to 44.0cm ² @ 12 wks) 39% ↑ in left quadriceps femoris (34.6cm ² @ baseline to 47.9cm ² @ 12 wks) (p<0.05). |
| Stewart et al. 2004 Canada Downs & Black score=10 Pre-post N=9 | Population: Incomplete SCI; Gender: 8 males, 1 female; Mean time post-injury: 8.1 yrs Treatment: Body weight-supported treadmill training, 3 d/wk for 6 mo Outcome Measures: Treadmill performance; Muscle biopsy – Fibre type & Myosin heavy chain (MHC) analysis. | 1. Muscle biopsy: • ↑ mean muscle-fibre area of type I & IIa fibres (p<0.001) • ↓ in mean type IIax/IIx fibres (p<0.05) • ↓ IIx myosin heavy chain (p<0.05) • ↑ mean type IIa fibres (p<0.01) 2. Treadmill performance: • 135% ↑ treadmill velocity (p<0.05) • 55%, ↑ in session length (p<0.05) • amount of externally supported weight ↓ as the result of training (p<0.05) |
| Strength | | |
| Needham-Shropshire et al. 1997 USA/CA PEDro=8 RCT Initial N=43; Final N=32 | Population: Chronic Tetraplegia; Mean age: 18-45yrs; Gender: 31 males, 3 females; Mean time post-injury: 3yrs Treatment: Subjects randomly assigned to one of three groups: Group 1 – received 8 wks of neuromuscular stimulation (NMS) assisted arm ergometry exercise. Group 2 – received 4 wks of NMS assisted exercise, and then 4 wks of voluntary arm crank exercise. Group 3 (control group) – voluntary exercise for 8 wks without the application on NMS. Outcome Measures: Manual muscle test. | 1. No significant difference was found at the 4-week evaluation between Groups 1 and 2 or between Groups 2 and 3. 2. Subjects in Group 1 had a higher proportion of muscles improving one or more muscle grades after 4 weeks of NMS cycling compared with Group 3 (p<0.003). 3. Following the second 4 weeks of training, a significant difference was found between Groups 1 and 3 (p<0.0005) and between Groups 2 and 3 (p<0.03). 4. No statistical difference was found between Groups 1 and 2. |
| Glinsky et al. 2008 | Population: Intervention group: Mean | 1. No statistically significant evidence |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
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| Australia PEDro=8 RCT Initial N= 32 Final N= 29 | <p>age: 37±16 yrs; Gender: 12 males, 3 females; Control group: Mean age: 47±20 yrs; Gender: 15 males, 1 female</p> <p>Treatment: The intervention group carried out a progressive resistance exercise program on one wrist 3 d/wk for 8 wks. It consisted of three sets of 10 repetitions (maximum) of one wrist muscle group, which was increased if the participant could do more than 10 repetitions and decreased if 10 repetitions were not achieved.</p> <p>Control group received routine physiotherapy and occupational therapy with no progressive resistance exercise program for the wrist.</p> <p>Outcome Measures: Strength measured as maximal voluntary isometric torque in Nm, muscle endurance measured as fatigue resistance and participants' perceptions about use of their hands using the Canadian Occupational Performance Measure (COPM). Measurements were taken at the beginning of the program and at end of 8 wks.</p> | <p>was found to suggest that progressive resistance exercise does or does not increase strength and/or endurance. Although, an 11% increase in mean initial muscle endurance and an 8% increase in mean initial strength was noted in the experimental group compared to the control group</p> <p>2. The activities of daily living most frequently selected by participants as part of COPM assessment were using cutlery and lifting objects such as bottles and cups. The mean effects of progressive resistance exercise on these activities were -0.3 for participants' perceptions of performance and -0.3 for participants' satisfaction. This indicates that the experimental group did not perceive that progressive resistance exercise improved performance of or satisfaction with their activities of daily living compared with the control group.</p> |
| Alexeeva et al. 2011 USA PEDro=7 RCT N=35 | <p>Population: Fixed Track Group: Mean age: 37.3± 13 yrs ; Gender: 12 males, 2 females; Level of injury: ASIA C (17%), ASIA D (83%); Cause of injury: traumatic (100%) Treadmill Group: Mean age: 36.4±12.9 yrs ; Gender: 8 males, 1 female; Level of injury: ASIA C (36%), ASIA D (64%); Cause of injury: traumatic (100%) Physical Therapy Group: Mean age: 43.3±15.8 yrs ; Gender: 10 males, 2 females; Level of injury: ASIA C (11%), ASIA D (89%); Cause of injury: traumatic (75%), non-traumatic (25%)</p> <p>Treatment: Patients participated in a body weight supported training program (Fixed Track or Treadmill) or comprehensive physical therapy for 1hr/d, 3 d/wk for 13 wks.</p> <p>Outcome Measures: ASIA International Standard (AIS) manual muscle test (MMT)</p> | <p>1. The mean change in muscle strength increased by 6-9% across all groups.</p> <p>2. There was a significant increase in strength across all groups ($p<0.01$), but no difference between groups.</p> |
| Mulroy et al. 2011 USA PEDro=7 RCT N=80 | <p>Population: Exercise/Movement Optimization group: Mean age: 47±9 yrs; Gender: 31 males, 9 females; Level of injury: ASIA A (62%), ASIA B (23%), ASIA C (8%), ASIA D (2%), Unknown (5%) Control Group: Mean age: 47±12 yrs; Gender: 26 males, 14 females; Level of injury: ASIA A (62%), ASIA B (13%), ASIA C (13%), ASIA D (2%), UNKNOWN (10%)</p> | <p>1. Strength gains were significantly greater in the exercise/movement optimization group compared with the control group in all 4 motions tested ($p<0.01$).</p> <p>2. All muscle groups demonstrated a statistically significant increase in maximal torque production following the intervention in the</p> |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
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| | <p>Treatment: Patients received a shoulder home exercise program 3d/wk for 12 wks. Stretching, warm-up, and resistive shoulder exercises were included.</p> <p>Outcome Measures: Shoulder muscle force production using a handheld dynamometer</p> | exercise/movement optimization group ($p<0.05$). |
| <p>Hicks et al. 2003 Canada Downs & Black score=20 PEDro=5 RCT Initial N=34; Final N=24</p> | <p>Population: Chronic SCI; Age (range): 19-65 yrs; Level of injury: C4-L1; Time post-injury (range): 1-24 yrs</p> <p>Treatment: Intervention group participated in progressive arm ergometry exercise training and progressive resistance training in several upper body muscle groups twice weekly for 9 mo- each session offered on alternative days lasting 90-120 min.</p> <p>Outcome Measures: Muscle strength</p> | <ol style="list-style-type: none"> 1. Following training, EX group had 81% \uparrow sub maximal arm ergometry power output ($p<0.05$) & 1-35% \uparrow in upper body muscle strength ($p<0.05$). 2. Overall 11 in the EX group (exercise adherence 82.5%) and 13 in the control group completed the study. |
| <p>Jacobs et al. 2009 USA PEDro=5 RCT N=18</p> | <p>Population: Traumatic SCI: RT Group: Mean age: 33.7\pm8.0 yrs; Gender: 6 males, 3 females; Mean body mass: 72.3\pm18.3 kg; ET group: Mean age: 29.0\pm9.9 yrs; Gender: 6 males, 3 females; Mean body mass: 83.7\pm8.9 kg</p> <p>Treatment: Subjects participated in a series of testing sessions before and after a 12wk training period. Patients were randomly assigned to two groups. The endurance training (ET) group performed 30 min of arm cranking exercise using a Saratoga arm crank device during each session at 70%–85% of HR_{peak}. The resistance training (RT) group performed three sets of 10 repetitions at six Hammer Strength MTS exercise stations (including horizontal press, horizontal row, overhead press, overhead pull, seated dips, and arm curls) with an intensity ranging from 60% to 70% of 1 rep max (1RM).</p> <p>Outcome Measures: VO_{2peak}, Graded exercise test (GXT); assessed at baseline and at end of treatment (12 wks)</p> | <ol style="list-style-type: none"> 1. Significant effects of both modes of training (RT and ET) in the physiological responses to peak GXT were observed. 2. Muscular strength significantly increased for all exercise maneuvers in the RT group with no changes detected in the ET group 3. VO_{2peak} values were significantly greater after RT (15.1%) and ET (11.8%). 4. Both RT and ET study groups displayed significant increases in P_{peak} and P_{mean}. 5. Mean power increased 8% and 5% for the RT and ET groups, respectively, with no statistically significant differences apparent between groups. RT produced significantly greater gains in P_{peak} (15.6%) compared with ET (2.6%). 6. The RT group displayed significantly increased strength values ranging from 34% to 55% for the six exercise maneuvers. In contrast, the ET group did not display increases in muscular strength for any of the six exercises after 12 wks of training. |
| <p>Harness et al 2008 USA Prospective Controlled Trial Initial N=31, Final N=29</p> | <p>Population: Intense Exercise Group: Mean age: 37.8\pm3.6 yrs; Gender: 18 males, 3 females; Severity of Injury: ASIA A or B (12), ASIA C or D (9) Control: Mean age: 34.5\pm2.9 yrs; Gender: 8 males</p> <p>Treatment: Treatment group - multi-modal intense exercise program; Control group - self-regulated exercise.</p> <p>Outcome Measures: Medical Research Council scale (muscle strength)</p> | <ol style="list-style-type: none"> 1. At least one muscle increased in strength over 6 months in 15/21 treatment participants compared to 0/8 control participants ($p<0.0001$); in these 15, the mean number of muscles showing a change was 4.1 (3.2 in lower extremities). |
| Bjerkefors et al. 2006 | Population: Traumatic SCI: SCI Group: | <ol style="list-style-type: none"> 1. There was a main effect of kayak |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
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| Sweden Downs & Black score=20 Pre-Post N=20 | Mean age: 38±12 yrs; Gender: 14 males, 6 females; Mean body mass: 70.8±13.9 kg; Reference Group: Mean age: 35±10 yrs; Gender: 7 males, 3 females; Mean body mass: 76.5±12.7 kg Treatment: 10-wk period of kayak ergometer training using commercially available kayak ergometer (Dansprint, I Bergmann A/S, DK). Every week subjects completed 3x60 min training sessions of kayak ergometer training. Outcome Measures: Shoulder muscle strength | ergometer training with increased shoulder muscle strength (in the beginning and middle positions and independent of shoulder movement) after training in persons with SCI. 2. There was no interaction between training, movement and angular position or between training and movement, but an interaction was observed between training and angular position. 3. The SCI group had less shoulder muscle strength compared to the reference group but the difference was not statistically significant to draw conclusions. |
| Hartkopp et al. 2003 Denmark Downs & Black score=20 Prospective controlled trial N=18 | Population: HR: Age (range): 29-55yrs; Gender: 8 males, 4 females; Level of injury: C-5/6; Time post-injury (range): 5-38 yrs; LR: Age (range): 32-44yrs; Time post-injury (range): 4-27yrs Treatment: Wrist extensor muscles were stimulated (30min/d, 5 d/wk for 12 wks) using either a high-resistance (HR group) or low-resistance (LR group) protocol. Outcome Measures: strength and endurance of contractile properties, muscle metabolism, fatigue resistance measured at baseline and 12wks | 1. Maximum voluntary torque increased in the Hr group ($p<0.05$), but not the Lr group. 2. For the Hr group the electrically stimulated peak tetanic torque increased only at 15Hz ($p<0.1$), and the Lr group remained unchanged. 3. Resistance to fatigue increased ($p<0.05$) in both the Hr (42%) and Lr (41%). 4. For the Hr group, the cost of contraction decreased by 38% ($p<0.05$) and the half-time of phosphocreatine recovery was shortened by 52% ($p<0.05$). 5. Electrical stimulation of the wrist increases fatigue resistance independent of the training pattern, but only in the Hr group does increased muscle strength improve aerobic metabolism after training. |
| Griffin et al. 2009 USA Downs & Black score=19 Pre-Post N=18 | Population: Traumatic SCI: Mean age: 40±2.4 yrs; Gender: 13 males, 5 females; Mean time post-injury: 11±3.1 yrs Treatment: FES cycling performed on an Ergys2 automated recumbent bicycle 2–3 d/wk for 10 wks Outcome Measures: AIS scores | 1. Training week had a statistically significant effect on the ride time without manually assisted pedaling. Ride times during training weeks 5–10 were statistically greater than during week 1. 2. Lower extremity total AIS scores and the motor and sensory components of the AIS test were all significantly higher following training 3. |
| Durán et al.2001 Colombia Downs & Black score=16 Pre-post N=13 | Population: Paraplegia; Age (range): 17-38yrs; Gender: 12 males. 1 female; Severity of injury: ASIA A (85%), ASIA B (7.5%), ASIA C (7.5%); Time post-injury (range): 2-120 mo Treatment: 16 wk exercise program (4 wks adaptation, 1 wk enhancement, 11 wks specific program (3d/wk, 120 min/session) including mobility, | 1. Weight lifted pre-program vs. post-program: • Bench press - 46% ↑, 42.7 vs. 62.5 ($p=0.0001$) • Military press - 14% ↑, 60.0 vs. 68.3 ($p=0.0002$) • Butterfly press- 23% ↑, 52.3 vs. 64.2 ($p=0.0001$). 2. Repetitions pre-program vs. post- |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
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| | <p>coordination, strength, aerobic resistance and relaxation exercises.</p> <p>Outcome Measures: Max. strength of upper limbs: max. weight mobilized in one trial or number of reps in 30 sec; Progressive resistance arm crank test: 3 min warm up @ 0 watts, resistance ↑ every 2 min; done pre & post program.</p> | <p>program:</p> <ul style="list-style-type: none"> • Biceps (dumbbell) - 10%↑, 26.7 vs. 29.4 (p=0.0001) • Triceps (dumbbell) - 18% ↑, 35.8 vs. 42.4 (p=0.0001) • Shoulder abductors- 61% ↑, 8.8 vs. 14.2 (p=0.0001) • Abdominal in 1' - 33% ↑, 47.0 vs. 62.4 (p=0.009) • Curl back neck - 19% ↑, 112.3 vs. 134.0 (p=0.0001) <p>3. Arm Crank Test:</p> <ul style="list-style-type: none"> • Max. resistance ↑ from 90 watts to 110 watts post-program (p<0.001). |
| <p>Nash et al. 2007 USA Downs & Black score=16 Pre-post N=7</p> | <p>Population: Chronic Complete Paraplegia; Age (range): 39-58 yrs; Gender: 7 males; Mean time post-injury: 13.1 yrs</p> <p>Treatment: Circuit resistance training (CRT), 45/min, 3d/wk on non-consecutive days for 16 wks. Training consisted of low-intensity endurance activities, circuit resistance training, military press, horizontal rows, pectoralis (horizontal row), preacher curls, wide-grip latissimus dorsi pull-downs, and seated dips.</p> <p>Outcome Measures: Wingate Anaerobic test (power assessment); Strength testing; all @ baseline & 16 wks.</p> | <p>1. Anaerobic power:</p> <ul style="list-style-type: none"> • 6% ↑ in peak power (p=0.005) • 8.6% ↑ average power (p=0.001). <p>2. Strength:</p> <ul style="list-style-type: none"> • ↑ on all maneuvers from 38.6% to 59.7% (p<0.001). |
| <p>Jacobs et al. 2001 USA Downs & Black score=15 Pre-post N=10</p> | <p>Population: Chronic Paraplegia; Mean age: 39.4 yrs; Gender: 10 males; Mean time post-injury: 7.3 yrs</p> <p>Treatment: 12wk training program – 40-45 min/session, 3d/wk on non-consecutive days. Sessions included resistance training (weight lifting) and endurance training (arm cranking).</p> <p>Outcome Measures: Isoinertial strength testing; Isokinetic strength testing; @ baseline 4, 8 & 12 wks.</p> | <p>1. 16.1% ↑ peak power output (p<0.05).</p> <p>2. Isoinertial strength:</p> <ul style="list-style-type: none"> • Mean 21,1% ↑ after 12 wks (p<0.01) • Improvements noted every month. <p>3. Isokinetic strength:</p> <ul style="list-style-type: none"> • ↑ after 12 wks for the shoulder joint internal rotation, extension, abduction, adduction & horizontal adduction (p<0.05). |
| <p>Petrofsky et al. 2000 USA Downs & Black score=13 Prospective controlled trial N=90 (9/group)</p> | <p>Population: Paraplegia; Mean age: 24.9 yrs; Gender: 90 males</p> <p>Treatment: 10 wk training period – consisted of electrical stimulation of quad muscles with 10 groups examining different variations of session length, frequency of sessions and length of flexion-extension cycle used in exercise program.</p> <p>Outcome Measures: Isometric strength; 3 experiments were designed looking at: 1) the effect of the length of the training session on performance; 2) the number</p> | <p>1. Length of training session:</p> <ul style="list-style-type: none"> • Greatest ↑ in work capacity in group training for 30min/day vs. 5 or 15 min/day (p<0.01). • 30 min/day group: rate ↑ of training was more rapid. • Quad muscle strength was greater in 30 min/day group than others <p>2. Number of days training/wk:</p> <ul style="list-style-type: none"> • Working out 3 days/wk benefitted more than those that worked out for 1 day/wk or 5 days/ wk. • Those that worked out 3 & 5 |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
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| | of days of training/wk on performance; 3) the effect of the length of the extension-flexion cycle on training | <p>days/wk were significantly more improved ($p < 0.01$).</p> <ul style="list-style-type: none"> • 3 days/wk had greater isometric strength in the quads. <p>3. Length of extension-flexion cycle:</p> <ul style="list-style-type: none"> • \uparrow training effect was assessing training by total work which would be done over the 30 min pd. |
| <p>Gregory et al. 2007 USA Downs & Black score=11 Pre-post N=3</p> | <p>Population: Chronic SCI: Age (range): 22-61 yrs; Gender: 3 males; Level of injury: tetraplegia (2), paraplegia (1) Severity of injury: ASIA D (100%); Time post-injury (range): 17-27 yrs</p> <p>Treatment: 12 wks of lower extremity resistance training in combination with plyometric training (RPT) (2-3 d/wk for 30 sessions)</p> <p>Outcome Measures: Muscle max cross-sectional area (max-CSA) of knee extensor (KE) & plantar flexor (PF) - MRI; Peak isometric torque, time to peak torque (T20-80), torque developed in initial 220 ms of contraction (torque 220) & mean rate of torque development (ARTD) -Dynamometry; Voluntary activation deficits.</p> | <ol style="list-style-type: none"> 1. Peak torque production improved following RPT in KE (M=28.9%) & PF (M=35%). 2. \downarrow T (20-80), \uparrow torque (220) & \uparrow mean rate of torque development in both muscle groups. 3. PF & KE voluntary activation deficits \downarrow following RPT. |
| <p>Cameron et al. 1998 USA Downs & Black score=9 Pre-post N=11</p> | <p>Population: Chronic SCI: Age (range): 18-45 yrs; Gender: 10 males, 1 female; Level of injury: C4-C7</p> <p>Treatment: Testing of hybrid device, 8 wks of neuromuscular stimulation-assisted exercise with training sessions 3d/wk.</p> <p>Outcome Measures: Manual muscle test scores biceps, triceps, wrist flexors and extensors.</p> | <ol style="list-style-type: none"> 1. All subjects showed improvement in one or more of their manual muscle scores, with the most dramatic occurring in the triceps (mean \uparrow 1.1 for L triceps, 0.7 for R triceps) 2. Results show neuromuscular stimulation in combination with resistive exercise can be used safely and assists in the strengthening of voluntary contractions |

Discussion

Muscle Morphology

A variety of benefits related to gross muscle morphology have been demonstrated in numerous investigations employing multi-week progressive exercise programs of FES-assisted cycling in which lower limb muscles (i.e., typically quadriceps, hamstrings and gluteal muscles) are stimulated to produce cycling movements against resistance (Sloan et al. 1994; Hjeltne et al. 1997; Mohr et al. 1997; Chilibeck et al. 1999; Scremin et al. 1999; Crameri et al. 2004; Heesterbeek et al. 2005; Griffin et al. 2009). Each of these FES-assisted cycling programs consisted of a minimum of three 30 minute sessions per week with program duration ranging from 8 weeks to 1 year with progressive resistance customized to the individual participant. Of note, Heesterbeek et al. (2005) employed a hybrid FES-assisted cycling protocol in which upper limb cycling was also incorporated into the physical activity intervention and Scremin et al. (1999) had a 4 phase intervention in which the final phase consisted of adding upper limb ergometry to FES-assisted lower limb cycling. These were the only investigations that incorporated upper body exercise although outcome measurement was limited to the muscles of

the lower limb. All studies, other than that conducted by Crameri et al. (2004), were uncontrolled investigations incorporating either a prospective pre-post or retrospective case series study design. In addition, all of the studies were relatively small with sample sizes of 18 persons or less. Benefits to gross muscle morphology consisted of significant increases in total body lean muscle mass (Griffin et al. 2009), thigh muscle mass (Mohr et al. 1997), cross-sectional area of overall thigh muscle (Sloan et al. 1994; Hjeltne et al. 1997, Scremin et al. 1999) and overall thigh volume (Heesterbeek et al. 2005) as well as significant reductions in muscle atrophy (Mohr et al. 1997). Significant increases were also seen in overall cross-sectional area or mean muscle fibre cross-sectional area within individual muscles (Chilibeck et al. 1999; Scremin et al. 1999; Crameri et al. 2004).

Other forms of neuromuscular electrical stimulation resistance exercise training have also been shown to produce beneficial muscle adaptations. In a relatively large study, persons with complete denervation due to a conus or caudal lesion (n=20 completing) underwent a two year home-based progressive electrical stimulation program which culminated in 30 minute sessions, 5 days/week involving a combination of twitch and tetanic stimulation patterns focusing on quadriceps but also on gluteal, hamstring and other lower limb muscles (Kern et al. 2010). Quadriceps and hamstring muscle cross-sectional areas were significantly larger with training with these results being more pronounced for the quadriceps. Similarly, significant increases in quadriceps muscle cross-sectional areas were produced in 5 males with ASIA A SCI with a home-based, two day/week program over twelve weeks in which four sets of ten unilateral, dynamic knee extensions were elicited by appropriate stimulation (Mahoney et al. 2005). A later report extended these observations with similar results following 18 weeks (Sabatier et al. 2006).

Other modes of endurance-based resistance exercise also led to similar muscle adaptations. For example, sustained participation in body weight support treadmill training 2 or 3 times/week resulted in significant increases in overall muscle cross-sectional areas in the thigh and lower leg muscles (Giangregorio et al. 2005; Giangregorio et al. 2006; Carvalho et al. 2008) as well as increases in mean individual muscle fibre sizes (Stewart et al. 2004) and partial reversal of muscle atrophy (Giangregorio et al. 2006). Of note, Carvalho et al. (2008; 2009) conducted a controlled trial (n=15) which showed significantly greater increases in MRI-derived quadriceps cross-sectional area with neuromuscular stimulation combined with body-weight supported treadmill gait training as compared to that seen with conventional physiotherapy. This was conducted over a 6 month period after which the gait training was offered to the control group. Gait training sessions consisted of 20 minute sessions at a frequency of twice per week. To this point, of all studies noted in this section, each of the interventions were applied to individuals with chronic SCI (i.e., > 6 months post-injury) with the exception of Giangregorio et al. (2005) who performed body weight support treadmill training on those more newly injured (i.e., 2-6 months post-injury). In addition, across studies participants had mostly complete or in rare instances near-complete SCI (i.e., AIS A, B or C).

A novel methodology was employed by Crameri et al. (2004) to investigate the effects of load on these types of muscle adaptations. These investigators used a 45 minute/day, three day/week FES-assisted cycling exercise protocol over ten weeks in which only one leg of each study participant was permitted to cycle against minimal load. The contralateral leg was also provided similar stimulation parameters as the “cycling” leg but these were applied against a fixed load so as to provoke rhythmic isometric contractions of the quadriceps and hamstrings against resistance. Exercise progressions were implemented with increases to the work-rest cycle and not to resistance as is often done in trials of FES-assisted cycling ergometry. This controlled investigation demonstrated that the amount of resistance is important in producing a training

effect as greater increases in isometric force generation and muscle fibre cross-sectional area were demonstrated for the static, high-resistance training condition.

Additionally, muscle biopsies have been performed before and after training, permitting investigation of the effects of physical activity on fibre type. Following SCI, (especially in those with complete or near complete lesions), there is an established transformation of muscle fibres away from type IIa toward type IIx fibres reflecting a functional shift towards less aerobic, more easily fatigable muscle (Grimby et al. 1976; Round et al. 1993). This shift was reversed over ten weeks (Crameri et al. 2002) and also at 6 months of a 1 year program (Andersen et al. 1996) of three day/week FES-assisted cycling exercise and with six months of three day/week body weight-supported treadmill training (Stewart et al. 2004) as each of these studies reported an increase in type IIa fibres and a corresponding reduction in type IIx (or IIb) fibres following training. More interestingly, similar results were seen in Crameri et al.'s 2004 investigation of the effect of static load vs. dynamic minimal load conditions with shifts of type IIx to type IIa muscle fibres apparent for both conditions along with the additional finding of a significantly greater increase in type I fibres only for the static, high-resistance trained leg. This represents an even more dramatic adaptation toward the aerobic, oxidative capacity of muscle with this type of training. Kern et al. (2010) demonstrated similar findings with their home-based neuromuscular stimulation promotion with increases in muscle fibre size that reverses the atrophic processes noted in denervated muscle.

There is also some evidence that passive cycling using upper-body assistance to drive paralyzed leg muscles involving 2 day/week sessions over 12 weeks may be sufficient to prevent these inactivity-related shifts towards more "fast" type muscle fibers. Willoughby et al. (2000) demonstrated significant increases in mRNA expression for type IIa fibres (and also for type IIx fibres) in the presence of decreasing proteolytic activity typically associated with muscle degradation. This passive exercise was insufficient to produce a significant increase in muscle size as indicated by no change in thigh girth and it is important to note that the leg movement required upper body voluntary exercise.

Strength and Muscular Endurance

In contrast to those investigations assessing outcomes related to muscle morphology, those assessing strength or muscular endurance were much more diverse with respect to the exercise modes employed. Notably, seven investigators incorporated RCT study designs (Needham-Shropshire et al. 1997; Hicks et al. 2003; Hartkopp et al. 2003; Glinsky et al. 2008; Jacobs 2009; Alexeeva et al. 2011; Mulroy et al. 2011) despite the acknowledged difficulty in fully implementing such features as participant blinding with the physical activity interventions typically associated with this design (Ginis and Hicks 2005).

Of these RCTs, six of seven trials resulted in statistically significant increases in strength, although there were different training paradigms used to achieve these results across the trials. Needham-Shropshire et al. (1997) used a paired-randomization approach to assign subjects with chronic cervical SCI (n=27) to one of three groups: 1) those receiving 8 weeks of neuromuscular stimulation-assisted arm ergometry exercise (NMS); 2) those receiving 4 weeks of NMS assisted exercise followed by 4 weeks of voluntary arm crank exercise; and 3) those participating in a control condition – voluntary exercise for 8 weeks without the application of NMS. Muscle strength was assessed by manual muscle testing in the triceps and the largest treatment effect (i.e., more muscles showing an increase of at least one muscle grade) was seen in Group 1 subjects ($p<0.0005$) although there were also a significant number of muscles that demonstrated an increase in muscle grade in Group 2 ($p<0.03$) relative to the control

condition. In a pre-post study, Cameron et al. (1998) used a prototype of the NMS-assisted arm crank ergometer used by Needham-Shropshire et al. (1997) to elicit significant improvements to triceps muscle strength following a three days/week upper body training program conducted over eight weeks.

These results are consistent with those reported by Hicks et al. (2003) who conducted an RCT (n=34, with 11 of 21 completing in the exercise group) of a twice weekly progressive voluntary arm ergometry cycling and resistance training exercise program with sessions of 90-120 minutes over nine months. These investigators noted significant increases ($p<0.05$) in muscle strength for 3 different upper body maneuvers involving triceps, biceps and anterior deltoid bilaterally at nine months as compared to baseline, although these increases in muscle strength showed progressive improvement over the nine months.

Similarly, Mulroy et al. (2011) implemented an exercise/movement optimization initiative in which participants received a shoulder home exercise program consisting of a stretching phase, warm-up phase, and a resistive shoulder exercise phase 3 times/week for 12 weeks. There were statistically significant strength gains in all motions tested (elevation in the plane of the scapula, adduction, internal rotation, and external rotation) compared with the control group ($p<0.01$). Also, all muscle groups, for those in the intervention group, demonstrated increases in maximal torque production as measured by the Micro-FET handheld dynamometer following the intervention ($p<0.05$).

Alexeeva et al. (2011) compared two body-weight-supported (BWS) training devices; fixed track and treadmill and comprehensive physical therapy for improving walking speed. One of the secondary outcomes measured was muscle strength as determined by the ASIA International Standard Manual Muscle Test. The training program for all participants included 1 hour/day, 3 days/week for 13 weeks. There was a statistically significant increase in muscle strength across all groups ($p<0.01$), but no differences between groups. There was a mean increase of 6-9% in muscle strength across all three groups.

Jacobs (2009) compared a resistance training paradigm involving 3 sets of 10 repetitions across six stations at 60-70% of a maximal single effort vs endurance training for 30 minutes involving arm cranking at 70%-85% of peak HR in persons with neurologically complete paraplegia (n=18). There were 3 sessions/week over a 12-wk training period with standardized exercise progressions for both the resistance training and endurance training groups and participants were matched between groups by body mass and gender. Muscular strength was significantly increased ($p<0.01$) with resistance training for each of the 6 isotonic strength testing maneuvers corresponding to those involved for each of the resistance training stations. There were no strength changes apparent for those in the arm ergometry group (i.e., endurance training). However, muscular endurance, as indicated by performance on the Wingate anaerobic power test, was significantly improved with both forms of training, although these improvements were most pronounced with resistance training.

Harness et al. (2008) implemented an intense exercise (IE) initiative that included 6 categories (active assistance, resistance training, load bearing, cycle ergometry, gait training/supported ambulation, and vibration training). The intervention group participated in the exercise program for an average of 56 ± 6 days and 7.3 ± 0.7 hours per week over a six month time period. The results demonstrated that 15/21 subjects had increased muscle strength in at least one muscle with a mean of 4.1 muscles (3.2 lower extremities) compared with 0/8 subjects in the control group ($p<0.0001$). Muscle strength was measured as a secondary outcome to motor function.

The RCT conducted by Glinsky et al. (2008) failed to show statistically significant increases in strength or muscular endurance (i.e., fatigue resistance) in wrist extensor or flexor muscles that were at least partially paralyzed in persons with tetraplegia (n=32). There was an overall mean increase of 8% and 11% in strength and muscular endurance respectively with training vs no training groups but this was deemed clinically insignificant. This study involved a resistance training program involving 3 sets of 10 repetitions using a customized device that permitted those with even minimal force generation to participate in a progressive exercise program. These authors noted that unlike other trials (e.g., Hicks et al. 2003), all participants had at least some paresis although it should be noted that there was a slight imbalance between experimental (i.e., training) vs control (i.e., no training) groups with respect to a slightly greater impairment in participants in the training group (i.e., 9 vs 6 persons with ASIA A and 4 vs 0 persons with an initial muscle grade of 2).

A similar training system to that employed by Glinsky et al. (2008) was used by Hartkopp et al. (2003) to examine the effect of electrical stimulation on strength and fatigue resistance in wrist extensor musculature in persons with tetraplegia (n=12 completing trial). This RCT used the non-trained arm as a control and demonstrated significant strength gains with a high resistance protocol, but not a low resistance protocol – each involving 5, 30 min sessions/week over 12 weeks. The high resistance protocol consisted of stimulation against a maximal load, whereas the low resistance protocol used a resistance of 50% of maximal load. Both training protocols were effective in improving resistance to fatigue.

There were also several investigations involving mostly pre-post study designs resulting in improved muscle function with different forms of electrically-stimulated exercise. For example, FES-assisted cycling programs involving the lower limbs and of varying durations and frequencies have demonstrated beneficial effects on muscle function. Griffin et al. (2009) demonstrated improved ASIA motor (and sensory scores) for the lower extremity following FES cycling for 2-3 times per week over 10 weeks in a group of persons with mostly incomplete SCI from C4-T7 (i.e., 13 of 18 with incomplete SCI). In persons with complete chronic SCI, FES-assisted cycling is effective for improving resistance to muscular fatigue as indicated by increases to sustained torque generation with repetitive stimulation in programs employing as little as 3, 30 min sessions/week over 6 weeks (Gerrits et al. 2000). A more extensive long-term program involving 5, 1 hour sessions/week over 1 year also was effective in improving fatigue resistance as well as producing a fivefold increase in maximal electrically stimulated torque (i.e., strength of contraction), although this remained lower than in able-bodied individuals (Duffell et al. 2008). Interestingly, in a later study, Gerrits et al. (2002) demonstrated that fatigue resistance was improved more effectively by low frequency (i.e., 10 Hz) vs high frequency (i.e., 50 Hz) stimulation, although each was equally effective in improving force generation (i.e., tetanic tension development).

In addition, several investigators have employed other approaches to lower limb neuromuscular stimulation such as the long-term home-based stimulation program by Kern et al. (2008) which resulted in a near ten-fold increase in stimulation-elicited muscle force in addition to the benefits to muscle morphology noted above. Sabatier et al. (2006) conducted a smaller pre-post study (n=5 persons with complete SCI) of an eighteen week home-based neuromuscular electrical stimulation resistance training program involving bi-weekly quadriceps training comprised of four sets of 10 dynamic knee extensions against resistance while in a seated position. This resulted in significant increases in strength (i.e., weight lifted), as well as a 60% reduction in muscle fatigue ($p = 0.001$).

Given the results of these studies, it is clear that there are a variety of approaches involving neuromuscular stimulation to the lower limb that accrue benefits to muscle function. However, information regarding the minimum requirements with respect to frequency, intensity, duration of a training program and how each of these might interact with different patient subgroups remains to be definitively established. Interestingly, Petrofsky et al. (2000) conducted a study to assess the effect of altering various parameters associated with a ten week training program of quadriceps muscle stimulation. These investigators assigned subjects (n=90) to 10 different treatment groups and examined the effect of altering some of the parameters associated with individual treatment sessions. Greater strength changes were seen for 30 minute sessions as compared to 5 or 15 minute sessions and for 3 day/week training as compared to 1 or 5 day/week training programs. In addition, strength gains and total work capacity was optimized by incorporating a pattern of 3 s extension - 3 s flexion – 6 s rest as compared to longer or shorter durations of work-rest cycles. Several investigations of voluntary exercise employing pre-post study designs have demonstrated strength benefits (in addition to other benefits). These studies have been conducted mostly in persons with paraplegia and have included circuit resistance training for 3 days/week (Durán et al. 2001; Jacobs et al. 2001; Nash et al. 2007), a combination of resistance training and plyometric training (Gregory et al. 2007) and 3, 60 minute sessions/week of kayak ergometer training over 10 weeks (Bjerkefors et al. 2006).

Conclusions

There is level 2 evidence from a single study with support from several level 4 studies that an appropriately-configured program of functional electrical stimulation of lower limb muscles in persons with SCI produces muscle adaptations such as increasing individual muscle fibre and overall muscle size and may result in the prevention and/or recovery of muscle atrophy.

There is level 2 evidence from a single study with support from several level 4 studies that an appropriately-configured program of functional electrical stimulation of lower limb muscles in persons with SCI results in an increase in muscle fibre types with more aerobic (endurance) capabilities, (most notably a shift in type IIx to type IIa muscle fibres).

There is level 1 evidence from a single RCT with support from a single level 4 study that functional electrical stimulation-assisted upper limb cycle ergometry is capable of producing significant increases in upper limb muscle strength in persons with tetraplegia.

There is level 2 evidence from a single RCT that voluntary upper limb cycle ergometry is capable of producing significant increases in upper limb muscle strength in triceps, biceps and anterior deltoid in persons with SCI.

There is level 1 evidence from two RCTs that voluntary upper limb resistance exercise is effective in increasing upper limb muscle strength in persons with paraplegia.

There is conflicting level 1 evidence across two RCTs that electrical stimulation-assisted resistance training of paretic wrist extensors or flexors increases strength and fatigue resistance in persons with tetraplegia.

There is level 1 evidence from a single RCT that body-weight supported fixed track or treadmill training can increase muscle strength in persons with SCI. There is also level 4

evidence from three studies that suggests that body-weight supported treadmill training in persons with SCI produces muscle adaptations of increasing individual muscle fibre size and overall muscle size and may result in the prevention and/or recovery of muscle atrophy.

There is level 2 evidence from a prospective controlled trial and level 4 evidence from several pre-post studies that circuit resistance training and other forms of resistance training combined with other approaches may increase upper limb muscle strength in triceps, biceps and anterior deltoid in persons with tetraplegia and/or paraplegia.

Circuit resistance training, body-weight support treadmill training and functional electrical stimulation (upper and lower limbs) may be effective in increasing muscle strength and reducing atrophy, with the latter two more appropriate for those with great muscle impairment.

2.2 Physical Activity and Functional Improvement Including Activities of Daily Living

As demonstrated in the previous section, appropriately configured exercise has been demonstrated to increase muscle strength and reduce atrophy. Most rehabilitation professionals presume there is also a clear link between therapeutic exercise and functional improvement that might manifest in enhanced performance of activities of daily living (ADLs). The present section examines the literature that assesses the functional consequences of physical activity programming. As described in SCIRE Chapter: Rehabilitation Practices (Wolfe et al. 2010), there are numerous reports of substantial gains achieved over the period of inpatient rehabilitation for outcome measures associated with functional independence (e.g., Functional Independence Measure (FIM(TM))) but the definitive attribution of these gains to specific aspects of rehabilitation programming remains to be fully elucidated.

Table 2: Physical Activity and Functional Improvement Including ADLs

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|--|
| Alexeeva et al. 2011 USA PEDro=7 RCT N=35 | <p>Population: Fixed Track Group: Mean age: 37.3± 13 yrs ; Gender: 12 males, 2 females; Level of injury: ASIA C (17%), ASIA D (83%); Cause of injury: traumatic (100%) Treadmill Group: Mean age: 36.4±12.9 yrs ; Gender: 8 males, 1 female; Level of injury: ASIA C (36%), ASIA D (64%); Cause of injury: traumatic (100%) Physical Therapy Group: Mean age: 43.3±15.8 yrs ; Gender: 10 males, 2 females; Level of injury: ASIA C (11%), ASIA D (89%); Cause of injury: traumatic (75%), non-traumatic (25%) Treatment: Patients participated in a body weight supported training program (Fixed Track or Treadmill) or comprehensive physical therapy for 1hr/d, 3 d/wk for 13 wks. Outcome Measures: FIM (motor domain</p> | <ol style="list-style-type: none"> 1. There was a slight increase in FIM motor scores after training, but it was not significant. 2. There were significant improvements in balance pre-to-post in the PT group ($p<0.001$) and the Track group ($p<0.01$), but no significant difference for the Treadmill group. |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---|
| | component only); Tinetti Scale | |
| Klose et al. 1990 USA PEDro=5 RCT N=43 | <p>Population: Age (range): 18-45 yrs; Level of injury (range): C4-C6; Severity of injury: incomplete (43); Time post-injury: minimum of one year</p> <p>Treatment: Training blocks of either supervised physical exercise therapy (PET), neuromuscular stimulation, or electromyographic biofeedback. Group 1 received 8 wks each of EMG biofeedback followed by PET, group 2 received 8 wks each of EMG biofeedback followed by NMS, group 3 received 8 wks each of NMS followed by PET, and group 4 received 16 wks of PET (3d/wk).</p> <p>Outcome Measures: Manual muscle tests, self-care scores, mobility</p> | <ol style="list-style-type: none"> 1. Significant improvements were found for measures of mobility, self-care, and left arm manual muscle test scores ($p<0.05$). 2. The repeated measures component was significant for all of the outcome measures except the EMGs ($p<0.01$). 3. All exercise modes were effective. No difference was found on comparisons between groups. |
| Harness et al. 2008 USA Prospective, non-randomized, controlled trial Initial N=31, Final N=29 | <p>Population: Intense Exercise Group: Mean age: 37.8 ± 3.6 yrs; Gender: 18 males, 3 females; Severity of Injury: ASIA A or B (57%), ASIA C or D (43%) Control: Mean age: 34.5 ± 2.9 yrs; Gender: 8 males</p> <p>Treatment: Treatment group - multi-modal intense exercise program; Control group - self-regulated exercise.</p> <p>Outcome Measures: Motor gains via ASIA motor score</p> | <ol style="list-style-type: none"> 1. When compared to control participants, intense exercise participants had significantly larger clinical gains as measured by changes in ASIA motor score ($p=0.0001$). ASIA motor score changes were mostly attributed to lower extremity motor scores; lower extremity motor scores had a significant group difference ($p<0.04$), while upper extremity motor scores did not. |
| Bjekefors et al. 2006 Sweden Pre-Post N=10 | <p>Population: Mean age: 37.6 yrs (range: 24-60); Gender: 7 males, 3 females; Level of injury: T3-12; Severity of injury: ASIA A (70%), ASIA B (20%), ASIA C (10%)</p> <p>Treatment: Patients received kayak ergometer training for 60 min, 3d/wk for 10 wks.</p> <p>Outcome Measures: Sit-and-reach test, propelling tests, and transfer/propelling wheelchair tests.</p> | <ol style="list-style-type: none"> 1. Sit-and-reach test scores showed a significant improvement from pre- to post-intervention ($p<0.05$). There was a statistically significant improvement in mounting-a-platform, propelling 15m on a level surface and propelling 50m on an incline from pre-to post-training ($p<0.05$) 2. The results of the transfer test showed a 10% mean increase after training. |
| Bjerkefors et al. 2007 Sweden Pre-Post N=10 | <p>Population: Mean Age: 38 ± 12 yrs; Level of injury: T3-12; Severity of injury: ASIA A (70%), ASIA B (20%), ASIA C (10%)</p> <p>Treatment: Patients received kayak ergometer training for 60 min, 3d/wk for 10 wks.</p> <p>Outcome Measures: Anterior-posterior (AP) angular and linear displacement during forward, backward, and lateral translations; medio-lateral (ML) angular and linear displacement during lateral translations; trunk twisting angular displacement during lateral translation; postural stability.</p> | <ol style="list-style-type: none"> 1. There were significantly smaller AP angular trunk displacements during lateral translations when comparing post-training with pre-training ($p=0.038$). There were no differences in FWD or BWD translations. 2. Results demonstrated significantly smaller AP linear trunk displacements post-training compared to pre-training for all translations (LAT, FWD and BWD) ($p<0.05$). There was an effect of training on ML angular trunk displacement during lateral translations for kinematic response IV (trunk position 1s after the end of platform deceleration) ($p<0.05$). |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| | | <ol style="list-style-type: none"> There were no significant effects of training on ML linear displacement during lateral translations. There were statistically significant improvements in trunk twisting post-training ($p<0.05$). Patients' postural stability was improved post-training; patients' showed smaller rotational and linear displacements of the trunk. |
| Chen et al. 2006 USA Pre-Post N=16 | <p>Population: Mean age: 43.8 yrs (range: 21-66); Gender: 9 males, 7 females; Level of injury: tetraplegia (25%) and paraplegia (75%); Severity of injury: ASIA A (56%), C (19%), D (25%); Cause of injury: traumatic (93.75%) and non-traumatic (6.25%);</p> <p>Treatment: 12 wks of a weight management program (e.g., nutrition, exercise, behaviour modification training) + 1-30 min exercise session for 6 wks.</p> <p>Outcome Measures: Three self-reported statements measured on a 5-point scale (difficulty transferring difficulty putting on/taking off clothes and time required for a bowel movement).</p> | <ol style="list-style-type: none"> There was a statistically significant improvement in self-reports of difficulty transferring post-treatment ($p=0.004$). There was a statistically significant improvement in self-reports of difficulty putting on/taking off clothes post-treatment ($p=0.02$). Time required for a bowel movement improved with a mean change of - 27.5 minutes, but this improvement was not statistically significant ($p=0.27$). |
| Hetz et al. 2008 Canada Observational N=48 | <p>Population: Mean age: 39.48; Gender: 35 males, 13 females; Level of injury: tetraplegia (39.6%), paraplegia (60.4%); Severity of injury: complete (58.3%), incomplete (41.7%); Cause of injury: traumatic (81.3%), non-traumatic (18.8%)</p> <p>Treatment: Questionnaire</p> <p>Outcome Measures: Physical Activity Recall Assessment for People with Spinal Cord Injury (PARA-SCI)</p> | <ol style="list-style-type: none"> Although there were no statistically significant differences in terms of ADL participation between men and women and between individuals with paraplegia and tetraplegia, when compared to men, women spent more time with domestic and personal care activities and those with paraplegia spent more time transferring, cleaning, and preparing food, while individuals with tetraplegia spent more time engaging in dressing, toileting, and wheeling. VO₂ Max was significantly associated with increased participation in cleaning and wheeling ($p<0.05$). Wheeling, dressing, and toileting were positively correlated with moderate- and heavy-intensity LTPA ($p<0.05$). |
| da Silva et al. 2005 Brazil Downs & Black score=18 Prospective controlled trial N=16 | <p>Population: Chronic SCI with AISA A Experimental Group (EG): Age (range): 21-34 yrs; Gender: 7 males, 1 female; Time post-injury (range): 15-40 mo Control Group (CG): Age (range): 21-41 yrs; Gender: 7 males, 1 female; Time post-injury (range): 14-30 mo</p> <p>Treatment: Comparison of swimming program vs. normal daily activities upon discharge from rehabilitation (both groups received orientation class during rehabilitation on numerous SCI related</p> | <ol style="list-style-type: none"> Pre vs. post swimming program: <ul style="list-style-type: none"> Body care: EG - \uparrow ($p=0.01$), CG - \uparrow ($p=0.02$) Transference: EG - \uparrow ($p=0.00$), CG - \uparrow ($p=0.04$) Overall motor score= EG - \uparrow ($p=0.00$), CG - \uparrow ($p=0.01$) Overall FIM score = EG - \uparrow ($p=0.00$), CG - \uparrow ($p=0.02$) Other areas did not have significant changes in either group. |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|--|
| | <p>topics including swimming). Experimental group (EG): Swimming program with a Physical Educator professor, 2d/wk, 45 min each, consisting of a warm up, main exercise & cool-down.</p> <p>Outcome Measures: Functional Independence Measure (FIM) at discharge & follow-up (avg 4 mo post-discharge).</p> | <p>2. More significant ↑ (difference scores in EG vs. CG for transference (p=0.02), overall motor score (p=0.01) and overall score (p=0.01).</p> |
| <p>Hjeltne & Wallberg-Henriksson 1998 Norway Downs & Black score=16 Prospective controlled trial (dissimilar control group) N=20</p> | <p>Population: Exercise group: Level of Injury: tetraplegia (10); Severity of injury: AISA A (70%), ASIA B (30%); Mean time post-injury: 99 d Control Group: Level of injury: paraplegia (10); AISA A (100%); Mean time post-injury: 78 d</p> <p>Treatment: Exercise group: standard rehabilitation + arm ergometry (tetraplegia), 30 min/d, 3 d/wk for a 12-16 wk period; Control group: standard rehabilitation (paraplegia).</p> <p>Outcome Measures: Ability to perform activities of daily living (Sonnaas ADL index), muscle strength (manual muscle testing), physiological assessments (VO₂, load) collected pre, mid & post program.</p> | <p>1. Experimental (tetraplegia) and Control (paraplegia) groups were not compared for functional and strength scores. Otherwise:</p> <ol style="list-style-type: none"> ↑ in ADL ability from pre to post program in those with tetraplegia (p<0.001). ↑ in manual muscle scores from pre to post program in those with tetraplegia (p<0.001). Peak resistance to cycling increased over cycling program but VO₂ did not. |
| <p>Durán et al. 2001 Colombia Downs & Black score=16 Pre-post N=13</p> | <p>Population: Age (range): 17-38yrs; Gender: 12 males. 1 female; Time post-injury (range): 2-120 mo; Severity of injury: ASIA A (85%), ASIA B (7.5%), ASIA C (7.5%)</p> <p>Treatment: 16 wk exercise program (4 wks adaptation, 1 wk enhancement, 11 wks specific program)- 3d/wk, 120 min/session, containing mobility, coordination, strength, aerobic resistance and relaxation exercises.</p> <p>Outcome Measures: Functional Independence Measure (FIM), Wheelchair skills test and various strength/resistance and physiological measures collected pre & post program.</p> | <ol style="list-style-type: none"> ↑ FIM from pre to post program, 106 to 113 respectively (p<0.001). Reduced time for all 9 wheelchair skills from pre to post program, (p<0.04 or less). ↑ in work capacity (weight lifted and reps) pre to post program. Generally no sig. diff. in various physiological parameters. |
| <p>Sloan et al. 1994 Australia Downs & Black score=14 Pre-post N=12</p> | <p>Population: Age (range): 15-54 yrs; Gender: 7 males, 5 females; Severity of injury: complete (1), incomplete (11); Time post-injury (range): 2 -138 mo</p> <p>Treatment: Functional electrical stimulation (FES) induced cycling programme: 3d/wk for 3 mo, all programmes were individualized & gradual progressed to 30 min/session.</p> <p>Outcome Measures: Functional assessment: independence & activities of daily living (ADL) tasks, muscle testing (grade and size) collected pre & post programme.</p> | <ol style="list-style-type: none"> All incomplete SCI patients had subjective self-reported improvements in well-being & functional independence, namely walking, dressing, transferring and ADL tasks. Most muscles increased in area and strength. Variable changes in spasticity (2 people discontinued because of increases in spasticity). |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| <p>Dallmeijer et al. 1999 The Netherlands Downs & Black score=13 Pre-post Initial N=27, Final N=20</p> | <p>Population: Mean age: 40.3 yrs; Gender: 16 males, 4 females; Level of injury: paraplegia (11) tetraplegia (9);,; AISA B, C & D; Mean time post-injury: t1=331 d, t2=765 d Treatment: Described changes in first years post-discharge and examined effect of those participating in ≥ 1 hr/wk of sport vs. those with no activity on physical capacity. Outcome Measures: Standardized ADL tasks physical strain & performance time (ascending ramp, transfer, passing door, washing hands); Sport activity & health status questionnaire; physical capacity (strength, power, VO_2 on wheelchair ergometer test) collected @ discharge (t1) & follow-up (t2, mean time=1.2 yrs).</p> | <ol style="list-style-type: none"> 1. Description of participation, illness, musculoskeletal system complaints: <ul style="list-style-type: none"> • 8/20=sedentary, 12 participated in ≥ 1 hr/wk (Overall group mean= 2.5 hrs/wk). • 10/20=serious illness during time span (UTI, pressure sores, pain, intestinal problems, pneumonia). • 9/20 Musculoskeletal system complaints. 2. Physical strain: was reduced over the year for all ADL tasks, except hand washing. 3. Performance time: \downarrow in transfer & ramp only ($p<0.05$) between t1 and t2 but not for other ADL tasks. 4. Participation in sport was correlated with measures of improved physical capacity (no relationship with ADL was assessed). |
| <p>Effing et al. 2006 The Netherlands Downs & Black score=13 Pre-post (Single subject controlled design) N=3</p> | <p>Population: Chronic incomplete SCI; Age (range): 45-51 yrs; Gender: 3 males; Severity of injury: AISA C (75%), ASIA D (25%); Time post-injury (range): 29-168 mo Treatment: Body weight supported treadmill training 5d/wk for 30 min/session for 12 wks personalized to physical abilities. Outcome Measures: Perceived performance on activities of daily living (ADL) – Canadian Occupational Performance Measure (COPM); Semi-structured interview; Performance based walking – Walking Capacity Scale; Walking Speed – 7 m; Balance & Mobility - Get Up & Go Test. Collected at baseline, 6 wks – treatment, 12 wks – wash-out, 6 wks – follow-up, 6 mo.</p> | <ol style="list-style-type: none"> 1. Subject 1: <ul style="list-style-type: none"> • Perceived ADL performance: rather stable, \downarrow satisfaction during intervention phase ($p<0.01$). • Interview: walked further without rest, felt better overall • Walking speed: \uparrow speed with \downarrow steps ($p<0.05$) • Balance: \uparrow ($p<0.05$). 2. Subject 2: <ul style="list-style-type: none"> • Perceived ADL performance: \uparrow improvement during intervention into washout period ($p<0.01$) • Interview: transfer independently, \downarrow pain medications, \downarrow spasms, felt better overall • Walking performance: \uparrow ($p<0.01$) • Could not perform walking speed & balance tests. 3. Subject 3: <ul style="list-style-type: none"> • Perceived ADL performance: \uparrow improvement; however, not in the intervention phase ($p<0.05$). • Interview: sit longer in a wheelchair, more stability, walking ability with a cane, \downarrow pressure ulcers, felt better overall • Walking performance: \uparrow ($p<0.05$) • Balance: \uparrow ($p<0.01$). |

Discussion

Of the interventional studies noted in Table 2, eight studies could be described as examining functionally-based outcome measures as a primary measure. Of note, Klose et al. (1990) used an RCT design to examine the effect of four different combinations of conventional physical exercise therapy (PET i.e., strengthening, mat mobility, and transfer, self-care and wheelchair skills training), neuromuscular stimulation (NMS)-assisted exercise or EMG biofeedback training focused on the upper limbs of males and females with tetraplegia (C4-C6) who were at least 1 year post-injury (n=43, 39 completing). Treatment subgroups received one of the following: 1) 8 weeks each of EMG biofeedback followed by PET; 2) 8 weeks each of EMG biofeedback followed by NMS; 3) 8 weeks each of NMS followed by PET; 4) 16 weeks of PET. All four of these treatment groups showed significant improvement in mobility and self-care scores ($p<0.05$) although there were no differences between groups with each method was equally beneficial in terms of functional improvement.

Bjekefors et al. (2006b) and Bjekefors et al. (2007) implemented kayak ergometer training sessions for 60 minutes, 3/week for 10 weeks. The functional movements that were tested included sit-and-reach, propelling, and transfers as well as anterior-posterior angular and linear displacement, medio-lateral angular and linear displacement and trunk twisting to determine postural stability. There was a statistically significant improvement in the sit-and-reach test, mounting-a-platform, propelling 15m on a level surface and propelling 50m on an incline from pre-to post-training ($p<0.05$). The results of the transfer test showed a 10% mean increase after training. In the 2007 study, there were significantly smaller AP angular trunk displacements during lateral translations when comparing post-training with pre-training ($p=0.038$) although there were no differences in FWD or BWD translations. Results also demonstrated significantly smaller AP linear trunk displacements post-training compared to pre-training for all translations (LAT, FWD and BWD) ($p<0.05$). There was an effect of training on ML angular trunk displacement during lateral translations for kinematic response IV (trunk position 1s after the end of platform deceleration) ($p<0.05$). There were no significant effects of training on ML linear displacement during lateral translations. There were statistically significant improvements in trunk twisting post-training ($p<0.05$). Overall, patients' postural stability was improved; patients showed smaller rotational and linear displacements of the trunk post-training.

In the study by Hetz et al. (2008), participants completed the Physical Activity Assessment for People with Spinal Cord Injury (PARA_SCI). The authors' objective was to examine participation in activities of daily living (ADLs) and fitness-related factors (i.e., VO_{2max}). Although there were no statistically significant differences in terms of ADL participation between men and women and between individuals with paraplegia and tetraplegia, when compared to men, women spent more time with domestic and personal care activities and those with paraplegia spent more time transferring, cleaning, and preparing food, while individuals with tetraplegia spent more time engaging in dressing, toileting, and wheeling. VO_{2max} was significantly associated with increased participation in cleaning and wheeling ($p<0.05$). Wheeling, dressing, and toileting were positively correlated with moderate- and heavy-intensity LTPA ($p<0.05$).

da Silva et al. (2005) conducted a prospective controlled trial (n=16) examining the effect of a 4 month swimming program (45 minute 2x/week) on persons with complete SCI (14 with paraplegia) who had just been discharged from inpatient SCI rehabilitation. The primary outcome measure was the FIM and significant differences were noted for the FIM transfer subscale score ($p=0.02$), overall motor subscale score ($p=0.01$) and overall score ($p=0.01$) between those participating in the swimming program as compared to those in the control group who performed only their routine daily activities.

Duran et al. (2001) also incorporated the FIM in assessing the effects of a mixed exercise program involving three 120 minute sessions/week over 16 weeks. Participants were outpatients with paraplegia and 12 of 13 were ≥ 5 months post-injury (median 10 months). This structured program consisted of activities that were focused on mobility, aerobic resistance, strength, coordination, recreation and relaxation. Significant increases were seen in total FIM score relative to baseline ($p < 0.001$) and time was reduced for all nine wheelchair skills tested ($p < 0.04$ or less) associated with the exercise program. These benefits along with increases in strength and exercise capacity were seen in the absence of statistically significant changes in various physiological parameters (i.e., lipid profile, body composition) although each of these variables did approach significance ($p = 0.076$ to 0.2). Harness et al. (2008) also incorporated a multimodal intense exercise (IE) program that included active assistive, resistance training, load bearing, cycle ergometry, gait training/supported ambulation, and vibration training. The training occurred over 6 months with participants engaging in the exercise program for 56 ± 6 days. Post-training, ASIA motor scores demonstrated a statistically significant improvement in the IE group compared with the control group ($p = 0.001$). Lower extremity scores accounted for most of the ASIA motor score changes and were statistically significant ($p < 0.05$).

Alexeeva et al. 2011 also used the FIM (motor domain component only) as well as the Tinetti scale as secondary measures in a body-weight supported treadmill or fixed track program compared with conventional physical therapy. Participants in all groups engaged in therapy for 1 hour/day, 3 days/week for 13 weeks. They found a slight increase in FIM motor scores post-intervention, but it was not significant. However, they did find significant improvements in balance from pre- to post-testing in both the PT and Track group, but no significant difference for the Treadmill group.

Other investigations incorporated measures associated with the performance of ADLs or other functional measures as secondary objectives. Subjective self-reports of improved walking (with an aid), transferring, dressing and other tasks of daily living along with concomitant strength improvements associated with a FES cycling program were reported by Sloan et al. (1994) for all the incomplete study participants with chronic SCI ($n = 11$ of 12). Hjeltne and Wallberg-Henriksson (1998) demonstrated significant improvements in the Sunnaas ADL index and muscle strength in persons with tetraplegia in response to a 6-8 week program of 3 days/week 30 minute arm ergometry sessions. This latter investigation was conducted in persons with sub-acute SCI as part of inpatient rehabilitation. Without a suitable control condition, it was uncertain if these benefits were due to the arm ergometry intervention or other aspects of the rehabilitation program or were associated with natural recovery.

Conclusions

There is level 2 evidence from a low quality RCT that either 16 weeks of physical exercise therapy alone or a combination of 2, 8 week blocks of physical exercise therapy, neuromuscular stimulation or EMG biofeedback may enhance self-care and mobility scores.

There is level 2 evidence from a single prospective, controlled trial that a twice weekly swimming program conducted over 4 months immediately following rehabilitation discharge may enhance motor FIM scores. This finding of exercise-related enhancement of functional outcomes is generally supported by 6 additional level 4 studies that employ different modes of physical activity associated with either increases to overall FIM scores or improved performance of ADLs.

Prospective, controlled trials are required to better determine the relationship of physical activity programming and functional benefits. There is no evidence for a relationship between specific program parameters (e.g., mode, intensity, frequency, duration) that might be necessary to achieve particular benefits.

Generally physical activity programming may be useful in improving functional outcomes such as performance of ADLs, but specific exercise and program parameters are not readily available.

2.3 Physical Activity and Subjective Well-Being

Subjective well-being (SWB) refers to how people evaluate their lives. It is a broadly-defined construct that encompasses an array of factors such as psychological well-being, satisfaction with health and physical functioning, and overall life satisfaction. Within the general population, considerable research has shown that regular participation in physical activity is associated with improvements in a wide range of SWB outcomes. In contrast, relatively little research has examined the effects of physical activity on aspects of SWB among people living with SCI. Although a couple of Level 1 and 2 studies have been conducted, most research examining physical activity and SWB has been cross-sectional (e.g., Manns and Chad 1999; Muraki et al. 2000; Stevens et al. 2008; Tawashy et al. 2009) and is excluded from the present analysis. A wide range of SWB outcomes have been examined such as perceptions of community integration, pain, mood states, anxiety, perceived health, and self-efficacy. Some of these aspects and their relationship with physical activity are discussed in different chapters (e.g., community reintegration, pain). Other aspects (e.g., mood states, self-efficacy) have been examined in too few high quality studies to generate reliable conclusions, and have been excluded from the present analysis. Two aspects, depression and quality of life, have been relatively well-studied in relationship to physical activity. As such, this section reviews only those studies that have included a measure of depression or quality of life.

Table 3: Physical Activity and Subjective Well-Being

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|---|
| Hicks et al. 2003 Canada PEDro=5 RCT Initial N=43; Final N=34 | <p>Population: Intervention group: Mean age: 36.9 yrs; Level of injury: Tetraplegia (11), Paraplegia (10); Mean time post-injury: 7.7 yrs. Control group: Mean age: 43.2 yrs; Level of injury: Tetraplegia (7), Paraplegia (6); Mean time post-injury: 12.1 yrs.</p> <p>Treatment: Intervention group: A progressive exercise training program 2d/wk for 9 mo, alternate days, 90-120 min/d, consisting of warm up, upper extremity stretching & 15 -30 min of aerobic training. As the rate of perceived exertion ↓, workload was ↑. Some resistance training took place. Control group: Offered an education session,</p> | <ol style="list-style-type: none"> 1. Exercisers reported a trend of ↓ stress, ↓ depressive symptoms, ↑ satisfaction with their physical functioning than the controls (p=0.06). 2. Exercisers reported ↓ pain (p<0.01) and ↑ QOL (p<0.05). |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|---|
| | 2d/mo (with exercisers) on various topics. Outcome Measures: Perceived Quality of Life Scale (PQOL). | |
| Latimer et al. 2004 Canada PEDro=6 RCT Initial N=34; Final N=21 | Population: Intervention group: Mean age: 38.27 yrs; Gender: 3 males, 8 females; Level of injury: Tetraplegia (7), Paraplegia (4); Severity of injury: ASIA A (5), B (1), C (3), D (1); Mean time post-injury: 10.54 yrs; Control group: Mean age: 43.08 yrs; Gender: 2 males, 8 females; Level of injury: Tetraplegia (3), Paraplegia (7); Severity of injury: ASIA A (3), B (1), C (3), D (3); Mean time post-injury: 14.58 yrs Treatment: Intervention group: 9 mo exercise program - 2d/wk, small group exercise sessions, 60-90 min duration consisting of stretching, arm ergometry & resistance exercise with student volunteer personal trainers. Control group: Asked to continue normal daily activities and not begin an exercise routine within 9 mo although provided with an opportunity for education. Outcome Measures: Pain perception (two items from the Short Form Health Survey - SF-36); Perceived stress scale, Center for Epidemiological Studies Depression Scale (CES-D) | 1. Exercise group had lower stress, pain, and depression and greater life satisfaction than the control group. 2. The effects of exercise on depression were mediated by changes in stress. |
| Martin Ginis et al. 2003 Canada PEDro=6 RCT Initial N=34; Final N=34 | Population: Mean age= 8.6 yrs; Gender: 23 males, 11 females; Mean time post-injury: 10.4 yrs Treatment: Intervention group: 5 min of stretching, 15 -30 min of aerobic arm ergometry exercise & 45-60 min of resistance exercise, 2d/wk, in small groups. Control group: Asked to continue normal daily activities and not begin an exercise routine for 3 mo Outcome Measures: Perceived Quality of Life scale (PQOL); Centre for Epidemiological Studies Depression Scale (CES-D). | 1. After 3 months, when compared to controls, exercisers had: <ul style="list-style-type: none"> • ↑ QOL (p=0.007) • ↑ satisfaction with physical function (p<0.01) • ↑ satisfaction with physical appearance (p=0.007). • ↓ depression (p=0.02). |
| Latimer et al. 2005 Canada PEDro=1 RCT N=33 | Population: Intervention group: Mean age: 37.54 yrs; Gender: 9 males, 4 females; Level of injury: Tetraplegia (7), Paraplegia (6); Mean time post-injury: 9.23 yrs Control group: Mean age: 43.30 yrs; Gender: 5 males, 5 females; Level of injury: Tetraplegia (4), Paraplegia (6); Mean time post-injury: 15.70 yrs Treatment: Intervention group: A 6 mo exercise program 2d/wk in small groups (avg 3-5 people), ran by student | 1. At baseline, ↑ stress levels were related to ↑ depression rates (p<0.05). At 6 mos, the exercise group's stress and depression association had ↓ but remained significant in the control group (p<0.05). 2. At baseline, ↑ stress levels were associated to ↓ perceived QOL (p<0.05). At 3 & 6 mos, the exercise group's stress and QOL association |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|---|
| | volunteer personal trainers. Control group: Asked to continue normal daily activities and not begin an exercise routine within 6 mo Outcome Measures: Perceived Stress Scale (PSS); Centre of Epidemiological Studies Depression Scale (CES-D); Perceived Quality of Life (PQOL); measured at @ baseline, 3 & 6 mo | ↓, but remained ↑ across all time points for the control group ($p<0.05$). 3. Exercise was found to buffer the effects of stress on QOL & depression. |
| Alexeeva et al. 2011 USA PEDro=7 RCT N=35 | Population: Fixed Track Group: Mean age: 37.3± 13 yrs ; Gender: 12 males, 2 females; Level of injury: ASIA C (17%), ASIA D (83%); Cause of injury: traumatic (100%) Treadmill Group: Mean age: 36.4±12.9 yrs ; Gender: 8 males, 1 female; Level of injury: ASIA C (36%), ASIA D (64%); Cause of injury: traumatic (100%) Physical Therapy Group: Mean age: 43.3±15.8 yrs ; Gender: 10 males, 2 females; Level of injury: ASIA C (11%), ASIA D (89%); Cause of injury: traumatic (75%), non-traumatic (25%) Treatment: Patients participated in a body weight supported training program (TRK or TM) or comprehensive physical therapy for 1hour/day, 3 d/wk for 13 wks. Outcome Measures: Satisfaction with Abilities and Well-Being Scale (SAWS); Short Form Health Survey (SF-36) | 1. Immediately post-training 80% of the participants reported increased satisfaction with abilities and well-being and this was significant across groups ($p<0.05$). 2. There were no significant changes in the four items from the SF-36 within groups or between groups after training. |
| Anneken et al. 2010 Germany Retrospective Cross-Sectional; Observational N=277 | Population: Mean age: 41.7 ± 12.7yrs; Gender: 219 males, 58 females; Level of injury: Paraplegia (78.3%); Severity of injury: Complete (62.9%); Cause of injury: traumatic (79%), non-traumatic (21%); Treatment: Questionnaire Outcome Measures: QOL Feedback | 1. The most prominent differences between the physically active and physically inactive individuals occurred in the single scales of physical domain (physical capacity in everyday life, physical activity, and mobility); all $p<0.001$. In the single scales of the psychological domain, prominent differences were found in remedial exercises, energy, and self-confidence; all $p<0.001$. In this study, physical exercise and sport were identified as the main influencing determinants of QOL . |
| Mulroy et al. 2011 USA PEDro=7 RCT N=80 | Population: Exercise/Movement Optimization group: Mean age: 47±9 yrs; Gender: 31 males, 9 females; Level of injury: ASIA A (62%), ASIA B (23%), ASIA C (8%), ASIA D (2%), Unknown (5%) Control Group: Mean age: 47±12 yrs; Gender: 26 males, 14 females; Level of injury: ASIA A (62%), ASIA B (13%), ASIA C (13%), ASIA D (2%), UNKNOWN (10%) Treatment: Patients received a shoulder home exercise program 3d/wk for 12 wks. Stretching, warm-up, and resistive | 1. All of the SF-36 subscales except for general health and vitality demonstrated a statistically significant ($p<0.05$) improvement in scores for participants in the exercise/movement optimization group and no change for the control group. 2. Overall SQOL scores increased 10% following the intervention for the exercise/movement optimization group ($p<0.05$), but were unchanged |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|---|
| | shoulder exercises were included. Outcome Measures: Short Form Health Survey (SF-36); Subjective Quality of Life Scale (SQOL) | for those in the control group. |
| Chen et al. 2006 USA Score Pre-Post N=16 | Population: Mean age: 43.8 years (range: 21-66); Gender: 9 males, 7 females; Level of injury: tetraplegia (25%), paraplegia (75%); Severity of injury: ASIA A (56%), C (19%), D (25%); Cause of injury: traumatic (93.75%), non-traumatic (6.25%); Treatment: 12 wk of a weight management program (e.g., nutrition, exercise, behaviour modification training) + 1-30-min exercise session/wk for 6 wks Outcome Measures: General Well-Being Schedule | 1. Although there were small increases in general well-being schedule scores from baseline to 12 weeks and baseline to 24 weeks, they did not reach statistical significance ($p=0.12$). |
| Hicks et al. 2005 Canada Downs & Black score=18 Pre-post N=14 | Population: Chronic incomplete SCI: Age (range): 20-53 yrs; Gender: 11 males, 3 females; Level of injury: Tetraplegia (11), Paraplegia (3); Severity of injury: ASIA B (2), C (12); Mean time post-injury: 7.4 yrs Treatment: RoboticBody weight supported treadmill training (BWSTT) – up to 45 min, 3d/week, 144 sessions (12 mo) Outcome measures: Centre for Epidemiological Studies of Depression Scale (CES-D); Satisfaction with Life Scale (SWLS); Short-Form Health Survey (SF-36); all questionnaires administered every 36 sessions. | 1. ↑ life satisfaction & ↑ physical function satisfaction ($p<0.05$), after BWSTT. 2. No change in depression or perceived health. |
| Semerjian et al. 2005 USA Downs & Black score=15 Pre-post N=12 | Population: Mean age: 34 yrs; Gender: 8 males, 4 females; Level of injury: Tetraplegia (7), Paraplegia (5); Time post-injury (range): 1-30 yrs Treatment: 10 wk individualized exercise program, 2d/wk, using the Bowflex Versatrainer, the Active-Passive Trainer, the EasyStand 6000 Glider, and the Body Weight Support System treadmill trainer (BWST). Outcome Measures: Quality of Life Index-Spinal Cord Injury Version III (QLI-SCI III) – 4 subscales: Health & Functioning, Psychological, Social & Economic and Family; the Body Satisfaction Questionnaire (BSQ); Semi-structured interview; Field notes taken during each session; Questionnaires done pre & post intervention, interview done post intervention. | 1. QOL: <ul style="list-style-type: none"> • ↑ health & functioning ($p<0.001$) • ↑ psychological ($p<0.05$) • ↑ social & economic ($p<0.05$) • ↑ overall QOL ($p<0.001$) • No change in family. 2. Body Satisfaction: <ul style="list-style-type: none"> • ↑ body functioning ($p<0.001$) • ↑ body attractiveness ($p<0.05$) 3. Interview & Field notes key themes: <ul style="list-style-type: none"> • Perceived health & physical ability improvement • Perceived ↑ in strength, endurance and attractiveness • Improved outlook on life • Psychological gains of standing exercise & BWST • Perceived recovery of function • Assistive device frustration • Independence importance |
| Ditor et al. 2003 Canada | Population: Mean age: 43.3 yrs; Gender: 5 males, 2 females; Time post- | 1. ↓ exercise adherence over the 3-mos follow-up period in comparison |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|--|
| Downs & Black score=14 Pre-Post N=7 | injury (range): 3-23 yrs Treatment: Patients who previously took part in a 9 mo exercise training program were given 3 mo (2 sessions/wk) of continued supervised exercise training in a laboratory setting. Outcome Measures: Exercise adherence (% of available sessions that were attended [max. 2/wk]), PQOL (11-item Perceived Quality of Life Scale with four additional SCI-relevant items), Pain (2 pain items from the Short-form Health Survey [SF-36]), Perceived Stress Scale | to the 9-mos adherence rate (42.7% versus 80.65%, respectively; $p<0.01$). 2. At 3 mos follow-up, \downarrow in PQOL ($p<0.05$). 3. Also, a trend was found for increased pain ($p=0.07$) and stress ($p=0.12$). 4. A significant negative correlation was found between pain scores at 9 mos and adherence during the 3 mos ($r=-0.91$; $P<0.01$). |
| Warms et al. 2004 USA Downs & Black score=14 Pre-Post Initial N=17; Final N=16 | Population: Mean age: 43.2 yrs; Gender: 13 males, 3 females; Mean time post-injury: 14.4 yrs Treatment: "Be Active in Life" program: included educational materials (2 pamphlets, 2 handouts), a home visit with a nurse (90 min scripted motivational interview, goal and personal action plan establishment), and follow up calls at day 4, 7, 11 & 28 (approx. 8 min each). Program lasted for 6 wks, and had a final follow up 2 wks post-completion. Outcome Measures: Physical activity (wrist-worn actigraph); Self-rated Abilities for Health Practices Scale (includes Exercise Self-efficacy subscale); Self-rated Health Scale (SRHS); Centre for Epidemiologic Studies Depression Scale (CES-D); @ baseline, 6 wk completion; 2 wks post-completion. | 1. Physical activity: Counts/day \uparrow in 60% of subjects and self-reported activity \uparrow in 69% of subjects, but both were not significant. 2. Self-rated abilities: no change. Exercise self-efficacy: \uparrow ($p=0.01$). 3. Self-rated health: \uparrow ($p=0.04$). 4. Depression: no change. |
| Effing et al. 2006 The Netherlands Downs & Black score=13 Case study N=3 | Population: Chronic incomplete SCI; Age range: 45-51 yrs; Gender: 3 males; Severity of injury: ASIA C (2), D (1); Time post-injury (range): 29-168 mo; Treatment: Body weight-supported treadmill training 5d/wk for 30 min for 12 wks, each session personalized to physical abilities. Outcome Measures: Perceived QOL: SEIQOL. | 1. QOL: \uparrow in only one subject ($p<0.05$). |
| Guest et al. 1997 USA Downs & Black score=13 Pre-post N=15 | Population: Traumatic complete paraplegia; Mean age: 28.8 yrs; Gender: 12 males, 3 females; Mean time post-injury: 3.8 yrs Treatment: Electrically stimulated walking program - 32 sessions, using the Parastep® FNS ambulation system. Outcome Measures: The Tennessee Self-Concept Scale (TSCS) - Physical Self subscale only; Beck Depression Inventory (BDI); measurements @ baseline & completion of program. | 1. Physical Self-Concept: \downarrow after electrically stimulated walking ($p<0.05$). Those with lower baseline score had the most significant improvements. 2. Depression: \downarrow after electrically stimulated walking ($p<0.05$). |
| Kennedy et al. 2006 | Population: Age (range): 18-61yrs; | 1. Significant improvement ($p=0.016$) in |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---|
| UK Downs & Black score=11 Pre-Post N=35 | Gender: 30 males, 5 females; Level of injury: Paraplegia (20), Tetraplegia (15) Treatment: Back-Up: a one wk single or multi-activity course in an integrated, residential environment. Activities include skiing, horseback riding, waterskiing, canoeing, rappelling, and gliding. Outcome Measures: Life Satisfaction Questionnaire, Hospital Anxiety and Depression Scale (HADS), Generalized Self- Efficacy Scale completed at baseline and end of 1 wk activity courses. | life satisfaction and satisfaction with leisure (p=0.007) 2. HADS scores demonstrated significant (p<0.01) improvement in anxiety but not depression levels over the duration of the course. 3. No overall improvement in perceived manageability however some difference (p=0.016) post test was observed for engage "in what happens around me" indicating some use of Perceived Manageability strategy. 4. Self-efficacy scores improved post test (p=0.012). |
| Bradley 1994 USA Downs & Black score=10 Cohort N=37 | Population: Mean age: 32.03 yrs; Gender: 24 males, 13 females; Level of injury: Tetraplegia (12), Paraplegia (25); Mean time post-injury: 6.51 yrs Treatment: Intervention group: 3 mo FES exercise program Outcome Measures: Multiple Affect Adjective Check List Revised state form (MAACLR) - Negative affect: anxiety, depression, hostility; Positive affect: positive affect, sensation seeking; Expectations of program recorded; all at baseline & post intervention. | 1. ↑ in depression & hostility for those who had unrealistic expectations of the FES program (p<0.01 & p<0.05, respectively). 2. No other significant effects were found. |

Discussion

With regards to depression, all but two studies (Hicks et al. 2005; Warms et al. 2004) showed positive effects of exercise on depressive symptoms (Guest et al. 1997; Hicks et al. 2003; Latimer et al. 2004; 2005; Martin Ginis et al. 2003). In addition, Kennedy et al. (2006) showed significant reductions in anxiety but not depression using the Hospital Anxiety and Depression Scale with their 1 week physical activity course. Given the variety of modes of physical activity examined in these studies, the consistent findings speak to the robustness of the relationship between physical activity and depression among people living with SCI. In the studies that showed no significant effects of exercise on depression (Hicks et al. 2005; Kennedy et al. 2006; Warms et al. 2004), participants' baseline depression scale scores were already extremely low, indicating minimal depressive symptomatology and very little room for improvement. As exercise has been shown to exert its greatest effects on people with greater depressive symptomatology, these findings are not particularly surprising.

With regards to quality of life, all of the Level 1, 2, and 4 studies showed that exercise training was associated with better quality of life (Mulroy et al. 2011; Alexeeva et al. 2011; Anneken et al. 2010; Ditor et al. 2003; Effing et al. 2006; Hicks et al. 2003; 2005; Kennedy et al. 2006; Latimer et al. 2004; 2005; Martin Ginis et al. 2003; Semerjian et al. 2005). Again, given that this association held across different types of physical activity modalities and in studies that used different measures of quality of life, the physical activity-quality of life relationship appears to be robust. However, the case-study by Effing et al. (2006) did not find quality of life improvements

for two of its three participants. When contrasted with the findings of the higher quality studies, these null findings speak to the importance of examining changes in quality of life over time, and in sufficiently large and representative samples, in order to properly assess the effects of physical activity on SWB.

How does physical activity improve depression, quality of life, and potentially other aspects of SWB? This question was examined in a series of papers using data from Hicks et al.'s (2003) RCT. Overall, these studies showed that exercise-induced reductions in stress and pain mediated the effects of exercise on quality of life and depression (Latimer et al., 2004; Martin Ginis et al., 2003). In other words, exercise training led to reductions in stress and pain, which, in turn, led to improvements in quality of life and depressive symptoms. Mulroy et al. (2011) also found a reduction in shoulder pain and an increase of 10% in subjective quality of life scores and an increase in all, but two, of the SF-36 subscales in the exercise/movement optimization group post-intervention with no change in the control group. There was also evidence that among people who were experiencing stressful life events, exercise helped to buffer the effects of the stress on their SWB (Latimer et al., 2005).

In general, several of the studies examining subjective well-being are constrained by an inadequate control group, making it difficult to discern whether it is the physical activity itself or some other aspect of a structured program that may be contributing to beneficial effects. Regardless, the conclusions below are based on the relative consistency across studies, despite these limitations. Of note, the trials conducted by Hicks et al. (2003) and Latimer et al. (2004) did provide an opportunity for education about exercise to their control group participants which afforded a more effective comparison than other trials which simply asked control group participants to maintain their usual activity patterns and defer initiation of an exercise program until after the study trial. Mulroy et al. (2011) also employed an education session for their attention control group. This session included a video and brochure regarding shoulder anatomy, mechanisms of injury, managing shoulder pain, and general shoulder care.

Conclusion

Based on level 1 and 2 evidence from 6 studies, exercise is an effective intervention for improving two aspects of SWB; quality of life and depressive symptomatology. For the most part, the level 4 and 5 evidence also supports this conclusion.

Emerging data from these studies suggest that changes in stress and pain may be the mechanisms underlying the effects of exercise on quality of life and depression. Further research is needed to examine other aspects of SWB in relation to physical activity.

Exercise is an effective strategy for improving at least two aspects of subjective well-being - depression and quality of life.

2.4 Physical Activity and Secondary Conditions

Numerous investigators and program planners have pointed to the occurrence of secondary complications or other health conditions that are encountered all too frequently by those with SCI as a means of providing rationale for their particular program of exercise or physical activity promotion (e.g., Rimmer 1999; Zemper et al. 2003; Block et al. 2005; Kosma et al. 2005). As noted previously, there is generally more support for an overall health benefit of physical activity in the able-bodied population including evidence for its role in the prevention of chronic disease

(US Department of Health and Human Services 1996; Warburton et al. 2006; Kruk 2007). The present section is intended to outline the evidence that exists in SCI for specific interventions involving physical activity in preventing or mitigating the effects of various secondary health conditions. Specific secondary conditions addressed include those associated with maintaining or enhancing cardiovascular health and bone health as well as preventing or mitigating disability associated with respiratory complications, pain, spasticity and periodic leg movements. The intent of this section is to bring the information about physical activity associated with various secondary health conditions into one place, as most of these secondary conditions comprise individual chapters within SCIRE. Therefore, we have referenced the existing chapters that contain information about physical activity interventions and to also bring forward the conclusions (i.e., evidence statements and bottom-line conclusions) from these chapters so the reader will gain a sense of the degree of evidence across these various conditions. The reader is encouraged to examine the referenced chapter for surrounding discussion and more information concerning the various studies and details about the specific interventions comprising the evidence. Of note, many of the therapies associated with upper limb or lower limb management involve therapeutic exercise programming (often associated with physical or occupational therapy) and for these we simply refer the reader to SCIRE Chapters: Upper Limb Rehabilitation Following Spinal Cord Injury (Connolly et al. 2010) and Lower Limb Rehabilitation Following Spinal Cord Injury (Lam et al. 2010) respectively.

2.4.1 Physical Activity and Cardiovascular Health

Cardiovascular disease, when considered after the first year post-injury within the US Model Systems database, has been acknowledged as the leading cause of death in persons with SCI, supplanting respiratory complications and previous to that septicaemia (Whiteneck et al. 1992; DeVivo et al. 1999). Cardiovascular disease is currently also the leading cause of death in the able-bodied population. A recent review by Myers et al. (2007) noted that there is a significantly high prevalence of cardiovascular disease in persons with SCI with rates of symptomatic cardiovascular disease in SCI of 30–50% in comparison to 5–10% in the general able-bodied population. Physical activity interventions comprise a significant part of the strategy in dealing with cardiovascular disease and the reader is referred to SCIRE Chapter: Cardiovascular Health and Exercise Following Spinal Cord Injury (Warburton et al. 2010) for more information on this topic. In the following section, we present those specific evidence-based statements and bottom-line conclusions from this chapter related to physical activity.

Conclusions - From SCIRE: Cardiovascular Health and Exercise Following SCI

Exercise Rehabilitation and Cardiovascular Fitness

Treadmill training

There is level 1b evidence (Millar et al. 2009) that BWSTT improves cardiac autonomic balance in persons with tetraplegia and paraplegia (with similar results for varying degrees of lesion level and severity).

There is level 4 evidence that BWSTT increases peak oxygen uptake and heart rate, and decreases the dynamic oxygen cost for persons with SCI.

There is level 4 evidence (Ditor et al. 2005a) that body-weight support treadmill training (BWSTT) improves cardiac autonomic balance in persons with incomplete tetraplegia.

There is level 4 evidence (de Carvalho and Cliquet 2005) that BWSTT can lead to improvements in cardiac autonomic balance in a subset of individuals with motor-complete SCI who respond to ambulation with moderate-to-large increases in heart rate.

Level 4 evidence (Ditor et al. 2005b) indicates that BWSTT can improve arterial compliance in individuals with motor-complete SCI.

There is level 2 evidence (de Carvalho et al. 2006) that neuromuscular electrical stimulation gait training can increase metabolic and cardiorespiratory responses in persons with complete tetraplegia.

There is limited evidence that BWSTT can improve indicators of cardiovascular health in individuals with complete and incomplete SCI.

Upper Extremity Exercise

There is level 1 evidence (Davis et al. 1987) that moderate intensity aerobic arm training (performed 20–60 min/day, three days/week for at least 6-8 weeks) is effective in improving the aerobic capacity and exercise tolerance of persons with SCI.

There is level 1 evidence (De Groot et al. 2003) that vigorous intensity (70–80% heart rate reserve) exercise leads to greater improvements in aerobic capacity than moderate intensity (50-60% heart rate reserve) exercise.

The relative importance of changes in cardiac function and the ability to extract oxygen at the periphery in persons with SCI after aerobic training remains to be determined.

There is level 2 evidence that hand cycling exercise increases the power output, oxygen consumption, and muscle strength in paraplegic, but not tetraplegic subjects during active rehabilitation. Conversely, there is level 4 evidence that hand cycling increases power output and oxygen consumption in subjects with tetraplegia.

Persons with tetraplegia and paraplegia can improve their cardiovascular fitness and physical work capacity through moderate intensities of aerobic exercise or resistance training, although optimal program parameters are not known.

Functional electrical stimulation (FES) – Lower Limb Cycle Ergometry and Hybrid (Upper and Lower Limb) and Other Electrically-Assisted Training Programs

There is level 4 evidence from pre-post studies that FES training performed for a minimum of three days per week for two months can be effective for improving musculoskeletal fitness, the oxidative potential of muscle, exercise tolerance, and cardiovascular fitness.

There is level 3 evidence (Jae et al 2008) that upper body exercise training can improve arterial structure and function in those with SCI.

There is level 4 evidence that FES training is effective in improving exercise cardiac function in persons with SCI.

There is level 5 evidence that arm-cranking exercise assisted by FES increases peak power output, and may increase oxygen uptake.

Based on the changes observed in VO₂max and findings from able-bodied individuals a consensus (level 5; Expert Opinion) was derived stating that aerobic training is effective in improving the ability to extract oxygen at the periphery in persons with SCI.

Interventions that involve FES training a minimum of 3 days per week for 2 months can improve muscular endurance, oxidative metabolism, exercise tolerance, and cardiovascular fitness.

Glucose Homeostasis

There is level 1 (De Groot et al. 2003) and level 4 (Chilibeck et al. 1999; Mohr et al. 2001; Jeon et al. 2002) evidence that both aerobic and FES training (approximately 20–30 min/day, three days/week for eight weeks or more) are effective in improving glucose homeostasis in persons with SCI.

There is level 4 evidence that the changes in glucose homeostasis after aerobic or FES training are clinically significant for the prevention and/or treatment of type 2 diabetes.

Aerobic and FES exercise training may lead to clinically significant improvements in glucose homeostasis in persons with SCI. Preliminary evidence indicates that a minimum of 30 min of moderate intensity training on 3 days per week is required to achieve and/or maintain the benefits from exercise training.

Lipid Lipoprotein Profiles

There is level 1 evidence (De Groot et al. 2003) to suggest that aerobic exercise training programs (performed at a moderate to vigorous intensity 20-30 min/day, 3 days per week for 8 weeks) are effective in improving the lipid lipoprotein profiles of persons with SCI. Preliminary evidence (level 4; Solomonow et al. 1997) also indicates that FES training (3 hours/week, for 14 weeks) may improve lipid lipoprotein profiles in SCI.

Aerobic and FES exercise training may lead to improvements in lipid lipoprotein profiles that are clinically relevant for the at-risk SCI population. The optimal training program for changes in lipid lipoprotein profiles remains to be determined. However, a minimal aerobic exercise intensity of 70% of heart rate reserve on most days of the week appears to be a good general recommendation for improving lipid lipoprotein profiles in persons with SCI.

2.4.2 Physical Activity and Respiratory Complications

Other than death due to external causes (e.g., motor vehicle accident, violence), respiratory complications have consistently been among the two leading causes of death in persons with SCI when considered after the first year post-injury, and the highest cause of death within the first year post-injury, over the past 35 years within the US Model Systems database (DeVivo et al. 1999). As noted in SCIRE Chapter: Respiratory Management Following Spinal Cord Injury (Sheel et al. 2008):

“The lungs and airways do not change appreciably in response to exercise training. It is likely that exercise is not sufficiently stressful to warrant an adaptive

response. This may be even more so when considering the small muscle mass used in wheelchair propulsion or arm cranking exercise. On the other hand, respiratory muscles are both metabolically and structurally plastic and they respond to exercise training. ... Exercise training may influence the control of breathing and respiratory sensations (i.e., dyspnea). It is generally accepted that exercise training results in a lower minute ventilation at any given absolute oxygen consumption or power output. This is likely due to a reduction in one or more of the mechanisms (neural and/or humoral) purported to cause the hyperpnea (increased respiratory rate) associated with exercise. As such, the positive effects of exercise training in SCI may reside in an increase in respiratory muscle strength and endurance as well as a reduced ventilatory demand during exercise."

For more information about these and other interventions related to exercise and muscle activation related to respiratory complications, the reader is referred to SCIRE Chapter 8 - Respiratory Management Following Spinal Cord Injury (Sheel et al. 2008). In the following section, we present those specific evidence-based statements and bottom-line conclusions from this chapter related to physical activity.

Conclusions - From SCIRE Respiratory Management Following SCI

Exercise Training

There is level 2 evidence (based on 1 prospective controlled trial) (de Carvalho et al. 2006) and level 4 evidence (based on 4 pre-post studies) (Silva et al. 1998; Sutbeyaz et al., 2005; Le Foll-de-Moro et al. 2005; Fukuba et al. 2006;) to support exercise training as an intervention that might improve resting and exercising respiratory function in people with SCI.

There is level 4 evidence (based on 1 pre-post study) (Janssen and Pringle 2008) that computer controlled electrical stimulation induced leg cycle ergometry (ES-LCE) increases the peak values of oxygen uptake, carbon dioxide production, and pulmonary ventilation.

For exercise training to improve respiratory function the training intensity must be relatively high (70-80% of maximum heart rate) performed three times per week for six weeks. Ideal training regimes have not been identified.

Inspiratory Muscle Training

There is level 1 evidence based (on 1 RCT) (Van Houtte et al. 2008), and level 4 evidence from several studies to support IMT as an intervention that might decrease dyspnea and improve inspiratory muscle function in some people with SCI.

There is limited evidence that inspiratory muscle training improves respiratory muscle strength or endurance in people with SCI.

2.4.3 Physical Activity and Bone Health

Osteoporosis is a condition characterized by low bone mass and deterioration of the skeletal system and is often cited as a secondary complication associated with SCI (Giangregorio and McCartney 2006; Jiang et al. 2006). This bone deterioration results in skeletal fragility and leads to an increased risk of fractures. Physical activity interventions have been suggested as potential strategies for both prevention and treatment of bone mineral density loss and the reader is referred to SCIRE Chapter: Bone Health Following Spinal Cord Injury (Ashe et al. 2010) for more information on this topic. In the following section, we present those specific evidence-based statements and bottom-line conclusions from this chapter related to physical activity.

Conclusions - From SCIRE Bone Health Following SCI

Non-Pharmacologic Therapy: Rehabilitation Modalities - Prevention (within 12 months of injury)

There is level 1 evidence (from one RCT) (Warden et al. 2001) that short-term (6 weeks) ultrasound is not effective for treating bone loss after SCI.

There is level 2 evidence (from 1 non-randomized prospective controlled trial) (Shields et al. 2006) that ES reduced the decline in BMD in the leg.

There is level 2 evidence (from 1 non-randomized prospective controlled trial) (Eser et al. 2003) that FES-cycling did not improve or maintain bone at the tibial midshaft in the acute phase.

There is level 4 evidence (from 1 pre-post study) (Giangregorio et al. 2005) that walking and level 1 evidence (from 1 RCT) (Ben et al. 2005) that standing in the acute phase did not differ from immobilization for bone loss at the tibia.

Short term (6 weeks) therapeutic ultrasound is not effective for preventing bone loss after SCI.

FES-cycling does not improve or maintain bone at the tibial midshaft in the acute phase but may increase/maintain lower extremity BMD the greater the time since injury.

Non-Pharmacologic Therapy: Rehabilitation Modalities - Treatment – Electrical Stimulation

There is level 2 evidence (from 1 prospective controlled trial) (Bélanger et al. 2000) that electrical stimulation either increased or maintained BMD over the stimulated areas.

There is level 4 evidence (from 1 pre-post study) (Melchiorri et al. 2007) that vibration training did not improve or maintain BMC in the arms.

Electrical stimulation can maintain or increase BMD over the stimulated areas.

Non-Pharmacologic Therapy: Rehabilitation Modalities – Treatment - FES Cycle Ergometry

There is level 4 evidence (from 1 pre-post study) (Chen et al. 2005) that 6 months of FES cycle ergometry increased regional lower extremity BMD over areas stimulated.

Six months of FES cycle ergometry may increase lower extremity BMD over areas stimulated.

Non-Pharmacologic Therapy: Rehabilitation Modalities – Treatment - Standing and Walking

There is inconclusive evidence for Reciprocating Gait Orthosis, long leg braces, passive standing or self-reported physical activity as a treatment for low bone mass

There is inconclusive evidence for Reciprocating Gait Orthosis, long leg braces, passive standing or self-reported physical activity as a treatment for low bone mass.

2.4.4 Physical Activity and Pain

Pain is a frequently noted complication in persons with SCI. Although reports vary widely, given historical variations in pain classification and differences in rating pain severity across the various pain categories (i.e., at-, above- or below-lesion neuropathic pain; visceral; musculoskeletal) it is generally established that an average of about two-thirds of people with SCI report some form of pain and nearly one-third of these rate their pain as severe (Siddall and Loeser 2001). Physical activity interventions have been linked to mitigating some of the effects of chronic pain in SCI and the reader is referred to SCIRE Chapter: Pain Following Spinal Cord Injury (Teasell et al. 2010) for more information on this topic. In the following section, we present those specific evidence-based statements and bottom-line conclusions from this chapter related to physical activity.

Conclusions - From SCIRE: Pain Following SCI

Exercises for Post-SCI Pain

There is level 1 evidence from a single RCT (Martin Ginis et al. 2003) that a regular exercise program significantly reduces post-SCI pain.

Regular exercise reduces post-SCI pain.

Exercises for Shoulder Pain

There is level 2 evidence (from one RCT and one PCT) that a shoulder exercise protocol reduces the intensity of shoulder pain post-SCI.

There is level 4 evidence that the MAGIC wheels 2-gear wheelchair results in less shoulder pain.

Shoulder exercise protocol reduces post-SCI shoulder pain intensity.

2.4.5 Physical Activity and Spasticity

Spasticity, defined as “disordered sensori-motor control, resulting from an upper motor neuron lesion, presenting as intermittent or sustained involuntary activation of muscle” (Pandyan et al. 2005), is a frequent condition associated with SCI with as many as 78% of persons with chronic SCI reporting spasticity (Adams and Hicks 2005). Spasticity may not worsen with age or time, however uncontrolled spasticity has been suggested as having an impact on emotional adaptation, dependency, secondary health problems and environmental integration (Krause 2007). Physical activity interventions have demonstrated decreased spasticity in persons with SCI and the reader is referred to SCIRE: Spasticity Following Spinal Cord Injury (Hsieh et al. 2010) for more information on this topic. In the following section, we present those specific evidence-based statements and bottom-line conclusions from this chapter related to physical activity.

Conclusions - From SCIRE: Spasticity Following SCI

Interventions Based on Passive Movement or Stretching

There is level 1 evidence from a single study that passive ankle movements may not reduce lower limb muscle spasticity in persons with initial mild spasticity.

There is level 2 evidence from a single study supported by level 4 evidence from another study that hippotherapy may reduce lower limb muscle spasticity immediately following an individual session.

There is level 2 evidence that electrical passive pedaling systems have an effect on spasticity and hip, knee and ankle range of motion.

There is limited level 1 evidence from a single study that a combination of a 6 week course of neural facilitation techniques (Bobath, Rood and Brunnstrom approaches) and Baclofen may reduce lower limb muscle spasticity with a concomitant increase in ADL independence. More research is needed to determine the relative contributions of these therapies.

There is level 4 evidence from a single study that rhythmic, passive movements may result in a short-term reduction in spasticity.

There is level 4 evidence from a single study that externally applied forces or passive muscle stretch (applied in assisted standing programs) may result in short-term reductions in spasticity. This is supported by individual case studies and anecdotal reports from survey-based research.

Hippotherapy may result in short-term reductions in spasticity.

A combination of neural facilitation techniques and Baclofen may reduce spasticity.

Rhythmic passive movements may produce short-term reductions in spasticity.

Prolonged standing or other methods of producing muscle stretch may result in reduced spasticity.

Interventions Based on Active Movement (Including FES-assisted Movement)

There is level 2 evidence from a single study (Kesiktas et al. 2004) that hydrotherapy is effective in producing a short-term reduction in spasticity.

There is level 2 evidence from a single study that single bouts of FES-assisted cycling ergometry and similar passive cycling movements are effective in reducing spasticity over the short-term with FES more effective than passive movement.

There is level 4 evidence from three studies (Granat et al. 1993; Thoumie et al. 1995; Mirbagheri et al. 2002) that a program of FES-assisted walking acts to reduce ankle spasticity in the short-term (i.e., <24 hours).

There is no evidence describing the length and time course of the treatment effect related to spasticity for hydrotherapy or FES-assisted walking.

Active exercise interventions such as hydrotherapy and (FES) functional electrical stimulation-assisted walking may produce short-term reductions in spasticity.

2.4.6 Physical Activity and Periodic Leg Movements

Restless legs syndrome and the associated phenomena of periodic limb movement have been noted to occur relatively frequently in persons with SCI (de Mello et al. 1996; Lee et al.1996). In particular, periodic leg movements are characterized by rapid leg movements during sleep, especially ankle dorsiflexion combined with extension of the large toe and less frequently knee and/or hip flexion. These may occur for several minutes to several hours and may be associated with insomnia and daytime somnolence and the inherent effects this can have on one's quality of life.

Table 4: Physical Activity and Periodic Limb Movements

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|--|
| De Mello et al. 2002 Brazil Downs & Black score=18 Pre-Post N=12 | Population: Mean age: 31.6 yrs; Gender: 13 males; Level of injury: T7 and T12; Severity of injury: complete (13) Treatment: SCI volunteers participated in physical training program using an | 1. A significant decline in PLM rate was seen at 36h after maximum effort test, 12 h after last training, and 36 h after the last day of training (p<0.05). |

| Author Year Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| | arm crank ergometer for 44 days. Outcome Measures: Rate of periodic leg movement (PLM). Measurements were taken before training, 12 h after maximum effort test, 36 h after maximum effort test, 44 days after training, and 12 h after the last training (45th day), 36 h after last day of physical training. | |
| De Mello et al. 2004 Brazil Downs & Black score=17 Prospective controlled trial N=13 | Population: Mean age: 31.6 yrs; Gender: 13 males; Height: 162-180 cm; Weight: 42.8-72.7 kg; Level of injury: T7 and T12; Severity of injury: AISA A (13); Time since injury: 10-231 mo Treatment: Subjects received L-DOPA (200mg) in combination with benserazide chloride (50mg) or placebo, 1 hr before sleeping for 30d followed by a 15d washout period. Physical training was then administered on the subjects for 45d, 3 d/wk for an average of 30 min/d Outcome Measures: Rate of periodic limb movement (PLM). Measurements were taken 30d after drug treatment and 45d after physical training. | 1. Significant reduction in PLM rate was seen after administration of L-DOPA ($p<0.03$) and physical training ($p<0.02$). 2. No significant difference were seen between the two treatments. |
| De Mello et al. 1996 Brazil Downs & Black score=17 Pre-Post N=11 | Population: Mean age: 28 yrs; Gender: 11 males; Level of injury: T7 - T12; Severity of injury: complete (11) Treatment: Effect of physical training session. Subjects were admitted to a sleep clinic for 3 consecutive nights. Physiological evaluation was conducted on the first day and after physical training on the 3rd day. Outcome Measures: Total sleep time, time in REM, number of awakenings, number of leg movements. | Significant decrease was seen after physical activity in: 1. Total sleep time ($p<0.04$). 2. Time in REM ($p<0.01$). 3. Number of awakenings ($p<0.03$). 4. Number of leg movements ($p<0.03$). |

Discussion

Following 2 pilot studies showing positive effects with either a single session (de Mello et al. 1996) or multiple sessions (de Mello et al. 2002) of exercise training, de Mello and colleagues conducted a prospective controlled trial comparing the effect of 30 days of initial L-dopa or placebo treatment versus 45 days of three/week 30 minute aerobic arm ergometry exercise training sessions in reducing the incidence of periodic limb movements during sleep (de Mello et al. 2004). Participants were all male, with complete chronic paraplegia (AISA A, lesion levels between T7-T12) with participants crossing over from 1 treatment to the next. The incidence of periodic limb movements was determined with polysomnographic analysis conducted as part of a sleep study and the effect of each treatment was noted relative to a baseline period. There was a 15 day washout period between the drug and exercise treatments to limit any carry-over effects. Both treatments were equally effective in reducing the amount of periodic limb movements such that the authors suggested a physical activity intervention as the first line of treatment and treatment with dopaminergic agonists to be reserved for persons who prove refractory to the exercise approach (De Mello et al. 2004).

Conclusion

There is level 2 evidence from a single study and support from two additional pre-post trials that a 45 day period of 3/week 30 minute aerobic exercise sessions (arm cycle ergometry) is equally effective as L-dopa in reducing night-time periodic limb movements in persons with complete paraplegia.

Aerobic exercise is effective in reducing night-time periodic limb movements in persons with complete paraplegia.

3 Increasing Physical Activity Participation in SCI

It is generally accepted that physical activity is associated with numerous physical and psychological benefits for both the able-bodied and for persons with SCI. The previous section outlined numerous investigations providing evidence that various forms of physical activity and exercise programming are effective for a variety of SCI-related issues. Recently, the Physical Activity Guidelines for Adults with Spinal Cord Injury (Martin Ginis et al. 2011) were released. These guidelines suggest two sessions of aerobic activity and two sessions of resistance training per week. They also provide information regarding duration, intensity and physical activity examples.

There are few studies that are directed towards investigating interventions that are designed to increase participation in physical activity and also that provide the background information needed to effectively design these interventions. Even though it seems obvious and is generally assumed that participation in physical activity is severely limited in persons with SCI, the research base on existing levels of physical activity participation and the specific barriers that persons with SCI must overcome to participate is lacking.

It should be noted that determining participation levels and investigations of barriers to participation are not amenable to experimental investigation and typically do not involve an intervention, and therefore comprise subject areas which are typically not addressed according to SCIRE methodology. However, descriptions of the observational studies examining participation levels and barriers to participation are included here as an understanding of these factors is critical for rehabilitation care providers and health promoters to successfully develop and apply physical activity-promoting interventions directed toward persons with SCI. Finally, the effectiveness of interventions that promote physical activity participation of persons with SCI is assessed from the existing literature.

3.1 Physical Activity Participation Levels in SCI

Although it is often stated that people with SCI are the most physically inactive segment of society, surprisingly few studies have actually measured physical activity in the SCI population. This lack of research is partly due to the fact that, until recently (Latimer et al., 2006a), there was no valid and reliable measure of physical activity for people with SCI that could be used in large-scale studies. Although several smaller studies (i.e., $n < 50$) have reported on physical activity levels among persons with SCI, given the considerable heterogeneity of the SCI population, the results of these studies are not necessarily generalizable. Thus, for the purpose of this review, we have focused only on larger-sample investigations.

Estimates of physical activity are affected by the approaches used to define and measure physical activity in a given study. In the reviewed studies, physical activity has been defined both narrowly (e.g., participation in sports activities), and more broadly to capture participation in

all activities requiring physical exertion (e.g., leisure-time physical activity, activities of daily living), and even some “exercise” activities that are not at all exerting (e.g., relaxation exercises). With regard to measurement, all of the larger studies utilized self-report measures of physical activity, with considerable variability in the types and amounts of physical activity information collected. This information has ranged from simply the rate of participation in the sample, to more comprehensive data on the types of physical activities performed, and in some cases, participation frequency, duration, or intensity.

Table 5: Physical Activity Participation in the SCI Population

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|--|
| Martin Ginis et al. 2010a (part 1) Canada Downs & Black score=19 Cross-sectional telephone survey N= 695 | <p>Population: Mean age: 47.1±13.5 yrs; Gender: 531 males, 164 females; Mean time post-injury: 15.3±11.1 yrs</p> <p>Treatment: Data on physical activity and demographic / injury-related characteristics of SCI patients were collected through telephone interviews.</p> <p>Outcome Measures: Physical Activity Recall Assessment for persons with SCI (PARA-SCI).</p> | <ol style="list-style-type: none"> 1. Respondents reported a mean of 27.14±49.36 minutes of LTPA a day. 2. 50.1% of participants reported no LTPA whatsoever. 3. LTPA decreased as age and years post-injury increased. 4. Men were more active than women. 5. Manual wheelchair users were more active than power wheelchair users and persons using gait aids. 6. Participants with tetraplegia with C1–C4 and C5–C8, ASIA grade A–C level injuries were significantly less active than participants with ASIA grade D injuries and participants with paraplegia with ASIA grade A to C injuries. 7. Highest amounts of daily LTPA (≥21min/d) were associated with manual wheelchair use and T1 to S5, ASIA grade A to C injury. 8. Moderate LTPA (1–20min/day) was most associated with being female, 5 to 10 years post injury, and 21 to 33.8 years of age. 9. Inactivity (0min/d) was most associated with being male, greater than or equal to 11 years post injury, and greater than or equal to 33.8 years of age. |
| Martin Ginis et al. 2010b (part 2) Canada Downs & Black score=19 Cross-sectional telephone survey N= 347 (subsample of those reporting engagement in LTPA in Martin Ginis et al. 2010a | <p>Population: Mean age: 45.4±13.8 yrs; Gender: 270 males, 77 females; Mean time post-injury: 13.5±10.0 yrs</p> <p>Treatment: Data on physical activity of SCI patients was collected through telephone interviews.</p> <p>Outcome Measures: Physical Activity Recall Assessment (PARA-SCI). This was broken down by type and intensity of activity.</p> | <ol style="list-style-type: none"> 1. Participants reported 55.15±59.05 min/day of LTPA at a mild intensity or greater. Median LTPA was 33.33min/d. 2. Participants engaged and spent significantly more time on moderate intensity LTPA than mild or heavy intensity LTPA, and more time on mild LTPA than heavy intensity LTPA. 3. Resistance training, aerobic exercise, and wheeling were the most frequently reported, whereas sports and craftsmanship activities were performed for the longest durations. 4. Activity duration differed as a function of activity intensity for resistance |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|--|---|---|
| | | <p>training, wheeling, craftsmanship, walking, play, and standing.</p> <ol style="list-style-type: none"> Resistance training was done for more minutes at a moderate intensity than at heavy and mild intensities, and for more minutes at a heavy intensity than a mild intensity. Craftsmanship, play, and wheeling were performed for more minutes at a mild or moderate intensity than at a heavy intensity. Walking and standing were done for more minutes at a moderate intensity than a heavy intensity. Resistance training, aerobic exercise, and general fitness activities were more likely to be performed at a moderate or heavy intensity than a mild intensity. There was no difference in the rate of participation in mild, moderate, or heavy intensity sport activities or in the amount of time spent performing mild, moderate, or heavy intensity activity for the general fitness activities, gardening, swimming, sports, or aerobic exercise. |
| <p>Tasiemski et al. 2005 UK Downs & Black score=14 Observational N=985</p> | <p>Population: Mean age: 28.6 yrs; Gender: 798 males, 198 females; Severity of injury: tetraplegia (343), paraplegia (642); Mean time post-injury: 19.5 yrs Treatment: Questionnaires mailed to participants. Outcome measures: The Sports Participation Questionnaire</p> | <ol style="list-style-type: none"> Sport Participation: ↓ in participation and hours spent involved in sports after injury versus before ($p<0.001$). 46.7% of participants currently engaged in sport and/or physical activity. A significant difference was found in those who participated before injury vs. after injury ($p<0.0001$): <ul style="list-style-type: none"> >6 hrs/wk: before=30%, after=9%. 3-5 hrs/wk: before=20%, after=10%. 1-2 hrs/wk: before=13%, after=11% Less than 1 hr/wk: before=7%, after=10%. None: before=19%, after=50%. |
| <p>Carpenter et al. 2007 Canada Downs & Black score=10 Observational N=357</p> | <p>Population: Mean age: 46 yrs; Severity of injury: complete (66%), incomplete (30%); Mean time post-injury: 13 yrs Treatment: Questionnaire Outcome Measures: British Columbia Paraplegic Association (BCPA) Survey</p> | <ol style="list-style-type: none"> Physical activity was the 3rd most common activity in respondent's social life. Factors that supported engaging in activities: <ul style="list-style-type: none"> family & peer support availability of transportation adaptive equipment clubs/advocacy organizations The majority of respondents would like to be able to engage in physical activities, sports & fitness (52%). |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|--|
| | | <ol style="list-style-type: none"> 75% of respondents were currently physically active. The most frequent activities were: <ul style="list-style-type: none"> a personal routine (67%) breathing & relaxation exercises (49%) weight training (45%) swimming (28%) 86% of participants engaged in "other activities" such as fishing, kayaking, ski-dooing, etc. Suggestions to increase participation: <ul style="list-style-type: none"> increased availability & accessibility exercise equipment accessibility Advice from a fitness trainer |
| Buchholz et al. 2003 Canada Observational N=27 | <p>Population: Mean age: 38.7±10.7 yrs (males), 31.7±6.0 yrs (females); Gender: 17 males, 10 females; Mean time post-injury: 12.5±9.5 yrs (range 1.5-39); Severity of injury: complete (17), incomplete (10)</p> <p>Treatment: Observation of physical activity</p> <p>Outcome Measures: % of sample who were obese; Physical Activity Level (as measured by Total Daily Energy Expenditure/Resting Metabolic Rate)</p> | <ol style="list-style-type: none"> 70.4% of the sample was obese. 56% of subjects engaged in physical activity 1.46±0.85 times during the study for a mean of 49.4±31.0 minutes. |

Discussion

Physical activity participation rates have been reported in four studies -- three Canadian, and one British. Notably, Martin Ginis and colleagues have reported results from a large cross-sectional study (n=695) based in Ontario, Canada designed to accurately measure the types, amounts, and intensities of LTPA (LTPA; defined as any physical activity that people choose to do during their spare time) performed by people with SCI (Martin Ginis et al. 2008; Martin Ginis et al. 2010a; Martin Ginis et al. 2010b). In these reports, which describe the methods and the baseline data from a prospective, longitudinal cohort study over 1.5 years, the initial overall participation rate was found to be 49.9% with these participants reporting a mean of 27.1 ± 49.4 minutes of LTPA a day, whereas 50.1% of participants reported no LTPA whatsoever (Martin Ginis et al. 2010a). Of those participants reporting >0 min/day of LTPA (n=347), there was a mean of 55.2 ± 59.1 min/day of LTPA at a mild intensity or greater with a median of 33.3 min/day (Martin Ginis et al. 2010b). Being male and greater than 11 years post-injury was associated with inactivity while having motor complete paraplegia and being a manual wheelchair user was associated with the most minutes of daily LTPA (Martin Ginis et al. 2010a). Although there was considerable variability among the activities preferred by individuals, most participants reporting LTPA did activities at a moderate level of intensity rather than mild or heavy and the 3 activities most frequently reported were resistance training, aerobic exercise and wheeling. The activities reported as being performed for the longest durations were craftsmanship and sports activities (Martin Ginis et al. 2010b).

In the other two Canadian studies (Buchholz et al. 2003; Carpenter et al. 2007), physical activity has been measured. Carpenter et al. (2007) reported that 75% of respondents participated in

“fitness activities” which included breathing and relaxation exercises (i.e., activities that do not necessarily require physical exertion or have fitness-enhancing benefits). This physical activity participation rate is significantly higher than that reported by Buchholz et al. (2003). The authors found that only 56% of subjects engaged in physical activity. The British study (Tasiemski et al. 2005) defined physical activity as involvement in sports and reported participation rates of just 47%. The large between-studies differences in participation rates likely reflect the broader range of activities measured in the Carpenter et al. (2007) study (i.e., activities that are not typically considered physical activities).

Information beyond simple participation rates was reported in three studies (Buchholz et al. 2003; Latimer et al. 2006a; Tasiemski et al. 2005) in addition to the aforementioned information noted by Martin Ginis and colleagues (2010a, 2010b). Buchholz et al. (2003) reported that subjects engaged in physical activity 1.46 ± 0.85 times during the study for a mean time of 49.4 ± 31.0 minutes each session; additionally, the authors found that 76.4% of subjects were obese. Tasiemski et al. (2005) reported that the most commonly practised sports were swimming, archery, weight-training, basketball, and table tennis. Of those who were active, about half spent 3-6 hours/week engaged in sports and the remainder were active for ≤ 2 hours/week. Latimer et al. (2006a) reported that on average, people with SCI spent 30 minutes/day engaged in LTPA and 213 min/day on activities of daily living that required at least mild intensity physical exertion. There was, however, tremendous variability in the amount of daily activity reported. Most of the LTPA was performed at mild and moderate intensities, and most of the activities of daily living were performed at a mild intensity. In general, men engaged in more LTPA than women, and younger people did more LTPA than older people. There were no differences in LTPA as a function of lesion level or completeness. It should be noted that the Latimer et al. (2006a) study was designed to validate a measure of physical activity for the SCI population (i.e., PARA-SCI) to be used in later larger-scale studies (i.e., Martin Ginis et al. 2010a; Martin Ginis et al. 2010b) rather than to measure LTPA in the SCI population. As a result, the study design and potential sampling biases may undermine the generalizability of their findings to the larger SCI population.

Conclusions

There is tremendous variability in the number of minutes of daily LTPA reported by persons with SCI. There is level 5 evidence from two large-sample studies and one small-sample study from different countries (i.e., Canada and UK) that approximately 50% of persons with SCI devote some time per week to sports, exercise, and other forms of LTPA.

There is level 5 evidence from a single study that a person with SCI participates in some form of LPTA for an average of about an hour per day (median ~ 30 minutes) when considering only the approximately 50% of people with SCI who are not inactive.

There is level 5 evidence from a single study that when physical activity is defined in terms of sports participation, the majority of people with SCI are considered inactive. There is level 5 evidence from a single study that indicates that most daily physical activity is accumulated in the form of activities of daily living when physical activity is defined in terms of participation in any activity that requires physical exertion.

There is tremendous variability in the amount of physical activity performed by people living with SCI. A large segment of the population does not engage in any leisure-time physical activity whatsoever.

3.2 Barriers to Physical Activity Participation in the SCI Population

The inactive lifestyle of individuals with SCI is a serious functional and health liability. Consequently, developing effective interventions to promote physical activity should be a research and public health priority (Rimmer 1999). In order to tailor interventions to the needs of individuals with SCI it is necessary to understand the factors affecting their participation in physical activity.

Among adult populations of persons with disabilities, frequently cited barriers impeding participation include: intrapersonal barriers (i.e., personal factors such as health concerns, motivation, and knowledge), systemic barriers (i.e., obstacles such as program costs and accessibility resulting from infrastructure and policy preventing participation or access), attitudinal barriers (i.e., stigma and negative stereotypes held by persons who are not impaired), and expertise barriers (i.e., gaps in practitioners' knowledge and skill to effectively prescribe and supervise physical activity for adults with a disability). The objective of this section is to examine the prominence of these barriers specifically in the SCI population. Indeed, barriers are a critical factor affecting participation in the SCI population (Latimer et al. 2004). For example, among a group of individuals with SCI exercising at an adapted exercise facility, participation rates were lowest among people experiencing more physical symptoms related to their injury (i.e., intrapersonal barriers; Ditor et al. 2003).

Table 6: Barriers to Physical Activity Participation in SCI

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|---|
| Arbour et al. 2009 Canada Observational N=50 | Population: Mean age: 43.5±12.7 yrs; Gender: 35 males, 15 females; Mean time post-injury: 13.8±10.4 yrs; Severity of injury: complete (15), incomplete (35); Wheelchair users: 52% manual Treatment: Questionnaire Outcome Measures: Perceived proximity to a fitness center compared to time spent participating in leisure time physical activity | 1. There was no significant association between leisure time physical activity and perceived proximity to a fitness center ($p<0.1$). |
| Kehn & Kroll 2009 USA Downs & Black score=16 Observational (Mixed Methods) N=26 | Population: Mean age (range): 23-74 yrs; Gender: 16 males, 10 females; Level of injury: Tetraplegia (14), Paraplegia (9); Severity of injury: complete (11), incomplete (9); Time post-injury (range): 1-32 yrs Treatment: Semi-structured interview guide was developed to explore core areas such as experiences with exercise before and after injury, logistics of current exercise regimen, barriers and facilitators of exercise, perceived benefits of exercise, perceived impact of exercise on secondary conditions. Each | 1. Non-exercisers had a significantly longer duration of injury ($p<0.05$). Other demographic and injury characteristics were not significantly different between exercisers and non-exercisers. 2. Similar barriers for both groups were reported. 3. Non-exercisers reported low return on physical investment, lack of facilities, equipment cost, fear of injury and lack of personal assistance as barriers to exercise. 4. Facilitators reported by exercisers |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|--|
| | interview lasted between 20 and 30 min. Analysis was conducted on patients who were exercisers vs. non-exercisers. Outcome Measures: Patients' experiences with exercise pre/post injury, barriers and facilitators to being active and perceived health impact measured after phone interview. | included motivation, availability of accessible facilities and personal assistants, weight management and fear of health complications. |
| Kerstin et al. 2006 Sweden Qualitative – Multiple Case Studies N=16 | Population: Mean age: 36.0±10.6 yrs (range 21-61); Gender: 12 males, 4 females; Mean time post-injury: 8.6±9.8 yrs (range 2-41); Severity of injury: tetraplegia (8), paraplegia (8) Treatment: In-person and telephone semi-structured interviews Outcome Measures: Major themes relating to the factors that promote participation in physical activity | <ol style="list-style-type: none"> Cognitive and behavioural strategies: <ul style="list-style-type: none"> role models creating routines and goals recalling previous experiences and acquiring new knowledge accepting assistance Environmental solutions: <ul style="list-style-type: none"> accessibility social support equipment and funding Motivation: <ul style="list-style-type: none"> gaining and maintaining independence improving physical appearance becoming a role model being competitive establishing a self-image as physically active becoming part of a social network New frames of reference: <ul style="list-style-type: none"> learning to live with narrower physical margins |
| Scelza et al. 2005 USA Downs & Black score=14 Observational N=72 | Population: Mean age: 44.1 yrs; Gender: 50 males, 22 females; Severity of injury: paraplegia - complete (36%), incomplete 11%; tetraplegia - complete (19%), incomplete (17%), ambulatory (17%); Mean time post-injury= 13.1 yrs Treatment: Cross-sectional survey Outcome Measures: The Barriers of Physical Exercise and Disability survey; The Perceived Stress Scale. | <ol style="list-style-type: none"> 73.6% wanted to be engaged in an exercise program and 79.2% thought it would be helpful. Despite this, only 45.8% were currently participating in an exercise program. Perceived Barriers: <ul style="list-style-type: none"> 37.5% health problems that caused a cessation in exercise (pain & fractures) 22.2% injured during exercise (strains & pulled muscles) 31.9% facilities (discomfort, lack of accessibility & privacy) Exercise Concerns <ul style="list-style-type: none"> 54.2% lack of motivation 41.7% lack of energy 40.3% program cost 36.1% lack of local exercise program knowledge 33.3% lack of interest 31.9% lack of time ↓ concerns in exercisers versus non-exercisers (p=0.016). Concerns - Tetraplegia ↑ than paraplegia: <ul style="list-style-type: none"> health issues cause a cessation in |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|--|--|---|
| | | <p>exercise (p=0.043)</p> <ul style="list-style-type: none"> • difficulty to engage in exercise (p=0.024) • health issue concerns prevented exercise (p=0.035) <p>6. ↑ levels of perceived stress were related to ↑ concerns (p=0.036).</p> |
| <p>Levins et al. 2004 USA Qualitative – Ethnography N=8</p> | <p>Population: Mean age: 42 yrs; Gender: 5 males, 3 females; Level of injury: T1-low thoracic levels; Mean time post-injury: 25.6 yrs; Treatment: Semi-structured interviews Outcome Measures: Major themes relating to barriers and facilitators to participation in physical activity</p> | <p>1. Individual influences:</p> <ul style="list-style-type: none"> • loss of an able identity • redefining self; turning points <p>2. Societal influences:</p> <ul style="list-style-type: none"> • environmental and attitudinal barriers • material environment (structural, financial) • societal attitudes |
| <p>Martin et al. 2002 Canada Downs & Black score=11 Observational N=15</p> | <p>Population: Group 1 (N=4); Mean age: 40 yrs (males), 19 yrs (females)-; Gender: 3 males, 1 female; Group 2 (N=6); Mean age: 38.5 yrs (males), 44 yrs (females); Gender: 4 males, 2 females; Group 3 (N=5); Mean age: 49.5 yrs (males), unknown (female); Gender: 4 males, 1 female. Treatment: Groups 1 & 2 were involved in an ongoing exercise program study. Group 3 was not in the study, but activity levels ranged from sedentary to regular. Each group engaged in a 1 hr focus session (open dialogue & discussion). Outcome Measures: Responses to open ended questions concerning exercise barriers, benefits and suggestions.</p> | <p>1. Barriers</p> <ul style="list-style-type: none"> • Accessibility – accessibility & affordability of program, transportation to program • Pain – soreness & stiffness • Psychological – depression, lack of confidence, worries & disappointment in abilities • Lack of information – failure of doctor to suggest exercise <p>2. Benefits</p> <ul style="list-style-type: none"> • Physical gains - ↑ muscle strength, ↑ ease of wheeling & ADLs. • Sense of well being - ↑ confidence and energy level <p>3. Facilitators</p> <ul style="list-style-type: none"> • ↑ accessibility • Personal trainers • Social support <p>4. Recommendations</p> <ul style="list-style-type: none"> • Self-monitoring – daily log, fitness testing • S.M.A.R.T. objectives (Griffin, 1998) – specific, measurable, accomplishment-oriented, realistic, time-bound • Safe, supervised & supportive environment • ↓ pain - stretching • ↓ transportation issues • Promote program |
| <p>Vissers et al. 2008 Netherlands Downs & Black score=11 Observational N=32</p> | <p>Population: Mean age: 45 yrs; Gender: 24 males, 8 females, Severity of injury: tetraplegia (12), paraplegia (20); Mean time post-injury: 103.5 mo; Years post-discharge 82.6 mo Treatment: Semi-structured interview. Outcome Measures: Response to retrospective & cross-sectional questions. 10 topic areas: subject &</p> | <p>1. Most important barriers:</p> <ul style="list-style-type: none"> • In current situation: store & building accessibility, physical & mental health issues. • After discharge: emotional distress, self-care difficulty & mental health problems. • ↑ importance of barriers after discharge vs. current situation. |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---|
| | lesion characteristics, daily physical activity, attitude towards an active lifestyle, social activities, health, quality of life, coping, care requirements, other factors. | 2. Most important facilitators: <ul style="list-style-type: none"> • In current situation: daily physical activity preparation, physical activity stimulation & social activity preparation, in rehab centre. • After discharge: social support (family, friends, society). |

Discussion

This series of seven observational (level 5) studies provide an indication of frequently encountered barriers and facilitators affecting physical activity participation in the SCI population (Arbour et al, 2009; Kehn and Kroll 2009; Kerstin et al., 2006; Levins et al. 2004; Martin et al. 2002; Scelza et al. 2005; Vissers et al. 2008;). Although all types of barriers as described above (i.e., intrapersonal, systemic, attitudinal, expertise, and societal) were cited as obstacles to physical activity participation, intrapersonal, systemic, expertise, and societal barriers were the most prominent and consistent. Arbour et al. (2009) did not find that proximity to a fitness center was related to the amount of time subjects spent in leisure time physical activity. Further research should determine which of these barriers are most influential and modifiable. In turn, practitioners and researchers should direct their efforts towards developing interventions to alleviate these key barriers.

One level 5 qualitative study (Kerstin et al. 2006) reported on factors that promote participation in physical activity among people with spinal cord injuries. The authors reported that four major themes were uncovered from the interviews as facilitators of physical activity participation: cognitive-behavioural strategies (e.g., accepting and becoming role models); environmental solutions (e.g., adequate social support); motivation (e.g., being competitive); new frames of reference (i.e., living within a narrower physical margin).

Interestingly, two of the studies suggest that the physical activity barriers that people with SCI encounter vary depending on lesion level and time post-injury. People with tetraplegia reported being more concerned about health conditions preventing exercise and exercise being too difficult than individuals with paraplegia (Scelza et al. 2005). Moreover, participants in the study by Vissers et al. (2008) indicated that they encountered more barriers to participation such as a need for more information and opportunity to participate in sport soon after discharge compared to later. Together these findings suggest that strategies for overcoming barriers to physical activity participation may be most effective when they are individualized to suit specific needs.

Conclusion

There is level 5 evidence from seven studies to suggest that individuals with SCI encounter a variety of factors that impede physical activity participation. Among these factors, the most frequently cited barriers include: (a) intrapersonal barriers such as perceived limited return on investment, health concerns and a lack of motivation, energy and time, (b) systemic barriers such as a lack of accessible facilities or unavailability of personal assistants, transportation difficulties, and program costs, and (c) expertise barriers such as a lack of knowledge about physical activity prescription and client referral processes.

A single level 5 study reported four areas that could promote participation in physical activity: cognitive-behavioural strategies, environmental solutions, motivation and new frames of reference.

Interventions are needed to help alleviate these obstacles. Further research must determine the most influential and modifiable barriers that would be optimal targets for intervention.

Individuals with SCI encounter numerous impediments to physical activity participation including intrapersonal, systemic, and expertise barriers. Interventions are needed to help people with SCI manage these barriers.

3.3 Effectiveness of Interventions to Increase Physical Activity Participation in SCI

The evidence that a large segment of the SCI population does not engage in any leisure-time physical activity whatsoever emphasizes the need for effective interventions to help people with SCI to become more physically active. In the SCI population, the majority of physical activity intervention studies are efficacy trials establishing the effects of physical activity on specific health outcomes. Few studies have examined strategies for increasing physical activity participation in this population. Thus, it is not surprising that programs and information to increase physical activity are two of the services most desired but least available to people with SCI (Hart et al. 1996; Boyd and Bardak 2004). To begin addressing this gap, this section reviews the physical activity intervention studies that include a measure of physical activity participation as a study outcome.

In the general population, three types of physical activity interventions have strong evidence of effectiveness: (1) Informational interventions that focus on delivering information to change knowledge and attitudes about the benefits of and opportunities for physical activity (e.g., a community-based media campaign), (2) Behavioural interventions that focus on teaching behavioural skills to promote physical activity participation (e.g., goal-setting), and (3) Environmental and policy interventions that focus on changing the physical environment, social networks, organizational norms and policies to enable physical activity participation (Kahn et al., 2002). Our review of physical activity interventions in the SCI population focuses solely on behavioural interventions. This narrow scope is due to the complete lack of research testing the effectiveness of informational and environmental interventions in the SCI population.

Table 7: Interventions Promoting Physical Activity Participation in SCI

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|---|--|
| Arbour-Nicitopoulos et al. 2009 Canada PEDRo=7 RCT Initial N=44 Final N=38 | Population: ACP condition group: Mean age: 49.00±12.93 yrs; Mean time post-injury: 18.01±14.16 yrs; Gender: 15 males=, 7 females; APO condition group: Mean age: 50.41±12.76 yrs; Mean time post-injury: 11.75±9.82yrs; Gender: 15 males, 7 females Treatment: Participants were randomly divided into either an action planning group (APO) or action coping planning | 1. LTPA participation was significantly greater at weeks 5 and 10 for the ACP condition in comparison with the APO condition group. The main effect for time or the time and condition interaction was not significant. 2. No difference was found in the frequency with which participants altered their original action plans over the 10-week period between ACP and |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---|
| | <p>(ACP) group. Informational, instructional and other materials to assist with exercise were provided to participants prior to initiating a 10 wk program. Both groups were facilitated in completing an action plan and the ACP group also developed a coping plan intended to assist in overcoming potential barriers.</p> <p>Outcome Measures: Leisure time physical activity (LTPA) participation as measured by a short version of the PARA-SCI, Intentions (2 Likert type questions), Coping self-efficacy, General barriers self-efficacy, Facility barriers self-efficacy, Scheduling self-efficacy, Health-related break from LTPA. Most measures were collected pre and post 10 wk intervention as well as mid-point (5 wks).</p> | <p>APO condition groups.</p> <ol style="list-style-type: none"> Participants in the APO condition did not spontaneously form coping plans over the 10 weeks. LTPA intentions decreased for both conditions over weeks 2 to 10. No significant main effect for condition or time and condition interaction was found. A significant medium-sized effect for time for general barriers self-efficacy was observed. Confidence to schedule moderate to heavy LTPA decreased for both groups over weeks 1 to 10. However, significant medium-large sized effects for condition were found for all 3 types of coping self-efficacy. Participants in the ACP condition group had greater confidence to schedule and overcome LTPA-related barriers compared to the APO condition group. The APO condition group had greater confidence to overcome facility-related barriers than did those in the ACP condition. For the intervention– coping self-efficacy relationship, the ACP condition group had greater scheduling and barrier self-efficacy, and lower facility related barriers than the APO condition group. |
| <p>Latimer et al. 2006b Canada PEDro= 4 RCT Initial N=54 ; Final N=37</p> | <p>Population: Chronic SCI; Mean age: 40.61 yrs; Gender: 16, males, 21 females; Level of injury: paraplegia (35), tetraplegia (19); Mean time post-injury: 19.34 yrs</p> <p>Treatment: Intervention group: Subjects and researchers created implementation intentions over the telephone, for 30 min of physical activity 3d/wk, for 4 wks. A 4 wk calendar and daily log book was emailed to the subject. After 4 wks, implementation intentions and calendars were updated for subsequent 4 wks. Control group: Subjects were advised by an interventionalist to engage in 30 min of physical activity 3d/wk, for 4 wks. Subjects verbally recited activities they would perform, and these were put into a calendar and emailed with a daily log book. After 4 wks, verbal recitation occurred again and a new calendar and daily log was received for a subsequent 4 wks.</p> <p>Outcome Measures: Intentions - 2</p> | <ol style="list-style-type: none"> Minutes of daily physical activity: ↑ when implementation intentions were utilized (p=0.04). The overall number of days subjects participated in ≥ 30 min of physical activity was not affected by intention implementation. The intentions-behaviour relationship was significantly stronger in the intervention group (p=0.03), as compared to the control group. Scheduling self-efficacy: ↑ at week 5 when implementation intentions were utilized (p=0.04). PBC and barrier self-efficacy did not differ between groups. |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|--|
| | <p>statements used: 1) "I will try to do at least 30 min of moderate to heavy physical activity 3d/wk over the next 4 wks" (1= definitely false; 7= definitely true);</p> <p>2) "I intend to do at least 30 min of moderate to heavy physical activity 3d/wk in the forthcoming month (1=extremely unlikely; 7=extremely likely); Physical Activity: Physical Activity Recall Assessment for Individuals with SCI (PARA-SCI); Perceptions of control (perceived behavioural control, PBC; scheduling self-efficacy; barrier self-efficacy).</p> | |
| <p>Zemper et al. 2003 USA PEDro=4 RCT Initial N=67; Final N=43</p> | <p>Population: SCI; Mean age: 47 yrs (range 22-80); Gender: 30 males, 13 females; Level of injury: paraplegia (18), tetraplegia (17), ambulatory (8); Mean time post-injury: 14 yrs (range 1-49)</p> <p>Treatment: Intervention group: 6 - 4 hr workshop sessions over 3 mo, which included lifestyle management, physical activity, nutrition, preventing secondary conditions, 3 individual coaching sessions, and 2 follow-up calls within 4 mos. after workshop. Control group: no intervention.</p> <p>Outcome Measures: Health Promoting Lifestyle Profile II; Secondary Conditions Scale; Self-rated Abilities for Health Practices scale (SAHP); Perceived Stress Scale; Physical activities with disabilities (PADS); Arm crank ergometer testing; neurologic exam; Body Mass Index (BMI); all at baseline and post-study.</p> | <ol style="list-style-type: none"> 1. When compared to control group, the intervention group showed statistically significant improvements in the following: <ul style="list-style-type: none"> • Health practice abilities (SAHP, $p<0.05$); • Health promoting lifestyle (HPLP-II, $p<0.001$); • Nutritional awareness and behaviour (HPLP-II subscale, $p<0.05$) • ↑ of stress management techniques, ↓ perceived stress (HPLP-II subscale, $p=.001$). 2. Secondary complications: ↓ in number, ↓ in severity, in the intervention group ($p<0.001$). A non-significant ↓ in depression was found. 3. Physical Activity (HPLP-II): ↑ physical activity and improved physical fitness ($p = 0.001$); however, no improvement on the PADs or physical fitness measures. |
| <p>Warms et al. 2004 USA Downs & Black score=14 Pre-Post Initial N=17; Final N=16</p> | <p>Population: SCI; Mean age: 43.2 yrs; Gender: 13 males, 3 females; Mean time post-injury: 14.4 yrs</p> <p>Treatment: "Be Active in Life" program: included educational materials (2 pamphlets, 2 handouts), a home visit with a nurse (90 min scripted motivational interview, goal and personal action plan establishment), and follow up calls at day 4, 7, 11 & 28 (approx. 8 min each). Program lasted for 6 wks, and had a final follow-up 2 wks post-completion.</p> <p>Outcome Measures: Physical activity (wrist-worn actigraph); Stage of Readiness for Change in Exercise Behaviour; Self-rated Abilities for Health Practices Scale (includes Exercise Self-efficacy subscale); Self-rated Health</p> | <ol style="list-style-type: none"> 1. Physical activity: Counts/day ↑ in 60% of subjects and self-reported activity ↑ in 69% of subjects, but both were not significant. 2. Barriers: ↓ in overall barrier score ($p=0.06$) and ↓ motivational barrier score ($p=0.01$). 3. Self-rated abilities: no change. Exercise self-efficacy: ↑ ($p=0.01$). 4. Self-rated health: ↑ ($p=0.04$) 5. Depression: no change. 6. Muscle Strength: only upper extremity muscle strength ↑ ($p=0.000$). |

| Author Year; Country Score Research Design Total Sample Size | Methods | Outcome |
|---|--|---------|
| | Scale (SRHS); Centre for Epidemiologic Studies Depression Scale (CES-D); Muscle Strength; @ baseline, 6 wk completion pt; 2 wks post-completion. | |

Discussion

Although the sample sizes (n=12-54) are small and the research methods are limited, the findings from the four published studies promoting physical activity for individuals with SCI are encouraging. Each of the level 1 and 2 studies (Arbour-Nicitopoulos et al. 2009; Latimer et al. 2006b; Zemper et al. 2003) reported a significant increase in physical activity participation following an intervention. The level 4 study (Warms et al. 2004) indicated a promising trend in which the majority of participants increased their participation over the course of the intervention.

In addition to providing evidence that physical activity participation in the SCI population is amenable to change, these studies begin to provide initial insight into essential intervention elements. All four studies used an established theoretical framework to guide the intervention content. Specifically, Zemper et al. (2003) developed their intervention based on self-efficacy theory (Bandura, 1986), Warmes et al. (2004) applied the transtheoretical model (Prochaska et al. 1992), Latimer et al. (2006b) used the action phase model (Gollwitzer, 1993), and Arbour-Nicitopoulos et al. (2009) employed both action planning and coping planning based on the Health Action Process Approach (Schwarzer, 1992) (See Table 9 for descriptions of these models and underlying concepts). The application of these theories in intervention development ensured that important determinants of physical activity behaviour were being targeted thus, boosting the odds of behaviour change.

Table 8: Descriptions of Theoretical Frameworks and Underlying Concepts

| Theoretical Framework or Concept | Description |
|----------------------------------|--|
| Self-Efficacy Theory | Self-efficacy is a central construct within Social Cognitive Theory, which was developed by Alfred Bandura (1986), and suggests that the observation of others within social interactions, media or other experiences is critical for knowledge acquisition. Self-efficacy is defined as the belief in one's ability to succeed in specific situations. In the context of interventions for increasing physical activity participation, self-efficacy is typically described as the confidence a person has in conducting the various behaviours required to engage in physical activity (e.g., overcoming barriers to participation, scheduling or in performing the specific physical activity itself). In addition to self-efficacy, other key determinants of social cognitive theory as applied to health promotion practices include knowledge of health risks and benefits, outcome expectations, health goals and associated strategies, and perceived facilitators and barriers (Bandura 2004). |
| Transtheoretical Model | The transtheoretical model (TTM) is a model of health behaviour |

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| | change that was developed by James Prochaska and colleagues in the late 1970's in the area of addictive behaviours (Prochaska and Velicer 1997). More recently, the core constructs of the TTM have been employed to guide the development of interventions that seek to promote physical activity participation (Marcus and Simkin 1994). These core constructs include stages and processes of change, decisional balance and self-efficacy. |
| Action Phase Model | The action phase model is a health behaviour change theory that specifies that goal-oriented behaviour consists of various phenomena such as deliberating, planning, acting and evaluating and that these are ruled by different principles (Gollwitzer, 1993). A significant aspect of this model is the importance of mind-sets in achieving successful behaviour change. For example, various techniques may be employed to assist the person to view goal attainment in a more positive light and avoid negative thoughts that might undermine their goal pursuits (Gollwitzer and Kinney, 1989). In turn, this positive thinking is thought to yield optimistic perceptions of control over the intended outcome. |
| Coping Planning (as part of the Health Action Process Approach) | Coping planning is a specific method that involves the pairing of anticipated barriers with self-regulatory strategies. Examples of self-regulatory strategies are self-monitoring or cognitive restructuring. By forming coping plans, persons may anticipate and develop plans to manage potential barriers that may interfere with goal attainment (Schwarzer 1992). |
| Implementation Intentions | Implementation intentions are action plans that specify when, where and how a goal is to be accomplished. Implementation intentions commit an individual to performing a behaviour within the situational cues (i.e., when, where, and how to act) as they are encountered (Gollwitzer, 1993). They have been identified as a useful technique that is consistent with the Action Phase Model. |

From the studies by Latimer et al. (2006b) and Arbour-Nicitopoulos et al. (2009), we begin to gain an understanding of the impact of a specific intervention strategy on physical activity participation. Latimer et al. (2006b) demonstrated that assisting persons with the creation of implementation intentions is a simple and efficacious intervention technique. Arbour-Nicitopoulos et al. (2009) extended these observations by incorporating a coping planning strategy as part of systematic action planning to circumvent anticipated barriers with self-regulatory strategies. Because the studies by Zemper et al. (2003) and Warms et al. (2004) delivered multifaceted interventions including education, goal setting, and barrier management counselling, the isolated impact of each of these intervention strategies remains unknown.

Conclusion

There is level 1 evidence from a single RCT and supported by two low quality RCTs and by an additional level 4 study that the physical activity behaviour of individuals with SCI is amenable to change, and that theory-based interventions may be a means of generating this change.

There is level 1 evidence from a single study that indicates that coping planning as part of action planning is an effective intervention technique for promoting physical activity participation in the SCI population.

There is level 2 evidence from a single study that indicates that facilitating the formation of implementation intentions may be an effective intervention technique for promoting physical activity participation in the SCI population.

More research is needed to identify additional, specific behavioural interventions that are effective in the SCI population. Furthermore, researchers should begin to consider the impact of other types of interventions including informational and environmental interventions.

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| Behavioural interventions promoting physical activity in the SCI population may lead to increased levels of physical activity participation. |
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4 Summary

There is level 2 evidence from a single study with support from several level 4 studies that an appropriately-configured program of functional electrical stimulation of lower limb muscle in persons with SCI produces muscle adaptations such as increasing individual muscle fibre and overall muscle size and may result in the prevention and/or recovery of muscle atrophy.

There is level 2 evidence from a single study with support from several level 4 studies that an appropriately-configured program of functional electrical stimulation of lower limb muscles in persons with SCI results in an increase in muscle fibre types with more aerobic (endurance) capabilities, (most notably a shift in type IIx to type IIa muscle fibres).

There is level 1 evidence from a single RCT with support from a single level 4 study that functional electrical stimulation-assisted upper limb cycle ergometry is capable of producing significant increases in upper limb muscle strength in persons with tetraplegia.

There is level 2 evidence from a single RCT that voluntary upper limb cycle ergometry is capable of producing significant increases in upper limb muscle strength in triceps, biceps and anterior deltoids in persons with SCI.

There is level 1 evidence from two RCTs that voluntary upper limb resistance exercise is effective in increasing upper limb muscle strength in persons with paraplegia.

There is conflicting level 1 evidence across two RCTs that electrical stimulation-assisted resistance training of paretic wrist extensors or flexors increases strength and fatigue resistance in persons with tetraplegia.

There is level 1 evidence from a single RCT that body-weight supported fixed track or treadmill training can increase muscle strength in persons with SCI. There is also level 4 evidence from three studies that suggests that body-weight supported treadmill training in persons with SCI produces muscle adaptations of increasing individual muscle fibre

size and overall muscle size and may result in the prevention and/or recovery of muscle atrophy.

There is level 2 evidence from a prospective controlled trial and level 4 evidence from several pre-post studies that circuit resistance training and other forms of resistance training combined with other approaches may increase upper limb muscle strength in triceps, biceps and anterior deltoids in persons with tetraplegia and/or paraplegia.

There is level 2 evidence from a low quality RCT that either 16 weeks of physical exercise therapy alone or a combination of 2, 8 week blocks of physical exercise therapy, neuromuscular stimulation or EMG biofeedback may enhance self-care and mobility scores.

There is level 2 evidence from a single prospective, controlled trial that a twice weekly swimming program conducted over 4 months immediately following rehabilitation discharge may enhance motor FIM scores. This finding of exercise-related enhancement of functional outcomes is generally supported by 6 additional level 4 studies that employ different modes of physical activity associated with either increases to overall FIM scores or improved performance of ADLs.

Prospective, controlled trials are required to better determine the relationship of physical activity programming and functional benefits. There is no evidence for a relationship between specific program parameters (e.g., mode, intensity, frequency, duration) that might be necessary to achieve particular benefits.

Based on level 1 and 2 evidence from 6 studies, exercise is an effective intervention for improving two aspects of SWB; quality of life and depressive symptomatology. For the most part, the level 4 and 5 evidence also supports this conclusion.

Emerging data from these studies suggest that changes in stress and pain may be the mechanisms underlying the effects of exercise on quality of life and depression. Further research is needed to examine other aspects of SWB in relation to physical activity.

There is level 4 evidence (Ditor et al. 2005a) that body-weight supported treadmill training (BWSTT) improves cardiac autonomic balance in persons with incomplete tetraplegia.

There is level 4 evidence (de Carvalho and Cliquet 2005) that BWSTT can lead to improvements in cardiac autonomic balance in a subset of individuals with motor-complete SCI who respond to ambulation with moderate-to-large increases in heart rate.

Level 4 evidence (Ditor et al. 2005b) indicates that BWSTT can improve arterial compliance in individuals with motor-complete SCI.

There is level 2 evidence (de Carvalho et al. 2006) that neuromuscular electrical stimulation gait training can increase metabolic and cardiorespiratory responses in persons with complete tetraplegia.

There is level 1 evidence (Davis et al. 1987) that moderate intensity aerobic arm training (performed 20–60 min/day, three days/week for at least 6-8 weeks) is effective in improving the aerobic capacity and exercise tolerance of persons with SCI.

There is level 1 evidence (De Groot et al. 2003) that vigorous intensity (70–80% heart rate reserve) exercise leads to greater improvements in aerobic capacity than moderate intensity (50-60% heart rate reserve) exercise.

The relative importance of changes in cardiac function and the ability to extract oxygen at the periphery in persons with SCI after aerobic training remains to be determined.

There is level 4 evidence from pre-post studies that FES training performed for a minimum of three days per week for two months can be effective for improving musculoskeletal fitness, the oxidative potential of muscle, exercise tolerance, and cardiovascular fitness.

There is level 4 evidence that FES training is effective in improving exercise cardiac function in persons with SCI.

Based on the changes observed in VO₂max and findings from able-bodied individuals a consensus (level 5; Expert Opinion) was derived stating that aerobic training is effective in improving the ability to extract oxygen at the periphery in persons with SCI.

There is level 1 (De Groot et al. 2003) and level 4 (Chilibeck et al. 1999; Mohr et al. 2001; Jeon et al. 2002) evidence that both aerobic and FES training (approximately 20–30 min/day, three days/week for eight weeks or more) are effective in improving glucose homeostasis in persons with SCI.

There is level 4 evidence that the changes in glucose homeostasis after aerobic or FES training are clinically significant for the prevention and/or treatment of type 2 diabetes.

There is level 1 evidence (De Groot et al. 2003) to suggest that aerobic exercise training programs (performed at a moderate to vigorous intensity 20-30 min/day, 3 days per week for 8 weeks) are effective in improving the lipid lipoprotein profiles of persons with SCI.

Preliminary evidence (level 4; Solomonow et al. 1997) also indicates that FES training (3 hours/week, for 14 weeks) may improve lipid lipoprotein profiles in SCI.

There is level 2 evidence (based on 1 prospective controlled trial) (de Carvalho et al. 2006) and level 4 evidence (based on 4 pre-post studies) (Silva et al. 1998; Sutbeyaz et al., 2005; Le Foll-de-Moro et al. 2005; Fukuoka et al. 2006;) to support exercise training as an intervention that might improve resting and exercising respiratory function in people with SCI.

There is level 4 evidence based on several studies to support inspiratory muscle training as an intervention that might decrease dyspnea and improve inspiratory muscle function in some people with SCI.

There is level 1 evidence (from one RCT) (Warden et al. 2001) that short-term (6 weeks) ultrasound is not effective for treating bone loss after SCI.

There is level 2 evidence (from 1 non-randomized prospective controlled trial) (Shields et al. 2006a) that ES reduced the decline in BMD in the leg.

There is level 2 evidence (from 1 non-randomized prospective controlled trial) (Eser et al. 2003) that FES-cycling did not improve or maintain bone at the tibial midshaft in the acute phase.

There is level 4 evidence (from 1 pre-post study) (Giangregorio et al. 2005) that walking and level 1 evidence (from 1 RCT) (Ben et al. 2005) that standing in the acute phase did not differ from immobilization for bone loss at the tibia.

There is level 2 evidence (from 1 prospective controlled trial) (Bélanger et al. 2000) that electrical stimulation either increased or maintained BMD over the stimulated areas.

There is level 4 evidence (from 1 pre-post study) (Chen et al. 2005) that 6 months of FES cycle ergometry increased regional lower extremity BMD over areas stimulated.

There is inconclusive evidence for Reciprocating Gait Orthosis, long leg braces, passive standing or self-reported physical activity as a treatment for low bone mass.

There is level 1 evidence from a single RCT (Martin Ginis et al. 2003) that a regular exercise program significantly reduces post-SCI pain.

There is level 2 evidence (from one RCT and one PCT) that a shoulder exercise protocol reduces the intensity of shoulder pain post-SCI.

There is level 4 evidence that the MAGIC wheels 2-gear wheelchair results in less shoulder pain.

There is level 1 evidence from a single study that passive ankle movements may not reduce lower limb muscle spasticity in persons with initial mild spasticity.

There is level 2 evidence from a single study supported by level 4 evidence from another study that hippotherapy may reduce lower limb muscle spasticity immediately following an individual session.

There is limited level 1 evidence from a single study that a combination of a 6 week course of neural facilitation techniques (Bobath, Rood and Brunnstrom approaches) and Baclofen may reduce lower limb muscle spasticity with a concomitant increase in ADL independence. More research is needed to determine the relative contributions of these therapies.

There is level 4 evidence from a single study that rhythmic, passive movements may result in a short-term reduction in spasticity.

There is level 4 evidence from a single study that externally applied forces or passive muscle stretch (applied in assisted standing programs) may result in short-term reduction in spasticity. This is supported by individual case studies and anecdotal reports from survey-based research.

There is level 2 evidence from a single study (Kesiktas et al. 2004) that hydrotherapy is effective in producing a short-term reduction in spasticity.

There is level 2 evidence from a single study that single bouts of FES-assisted cycling ergometry and similar passive cycling movements are effective in reducing spasticity over the short-term with FES more effective than passive movement.

There is level 4 evidence from three studies (Granat et al. 1993; Thoumie et al. 1995; Mirbagheri et al. 2002) that a program of FES-assisted walking acts to reduce ankle spasticity in the short-term (i.e., <24 hours).

There is no evidence describing the length and time course of the treatment effect related to spasticity for hydrotherapy or FES-assisted walking.

There is level 2 evidence from a single study and supported by two additional pre-post trials that a 45 day period of 3/week 30 minute aerobic exercise sessions (arm cycle ergometry) is equally effective as L-dopa in reducing night-time periodic limb movements in persons with complete paraplegia.

There is tremendous variability in the number of minutes of daily LTPA reported by persons with SCI. There is level 5 evidence from two large-sample studies and one small-sample study from different countries (i.e., Canada and UK) that approximately 50% of persons with SCI devote some time per week to sports, exercise, and other forms of LTPA.

There is level 5 evidence from a single study that a person with SCI participates in some form of LPTA for an average of about an hour per day (median ~ 30 minutes) when considering only the approximately 50% of people with SCI who are not inactive.

There is level 5 evidence from a single study that when physical activity is defined in terms of sports participation, the majority of people with SCI are considered inactive.

There is level 5 evidence from a single study that indicates that most daily physical activity is accumulated in the form of activities of daily living when physical activity is defined in terms of participation in any activity that requires physical exertion.

There is tremendous variability in the number of minutes of daily LTPA reported by persons with SCI. There is level 5 evidence from two studies that, although many report no activity whatsoever, there is a minority that devotes several hours per week to sports, exercise, and other forms of LTPA.

There is level 5 evidence from seven studies to suggest that individuals with SCI encounter a variety of factors that impede physical activity participation. Among these factors, the most frequently cited barriers include: (a) intrapersonal barriers such as perceived limited return on investment, health concerns and a lack of motivation, energy and time, (b) systemic barriers such as a lack of accessible facilities or unavailability of personal assistants, transportation difficulties, and program costs, and (c) expertise barriers such as a lack of knowledge about physical activity prescription and client referral processes.

A single level 5 study reported four areas that could promote participation in physical activity: cognitive-behavioural strategies, environmental solutions, motivation and new

frames of reference. Interventions are needed to help alleviate these obstacles. Further research must determine the most influential and modifiable barriers that would be optimal targets for intervention.

There is level 1 evidence from a single RCT and supported by two low quality RCTs and by an additional level 4 study that the physical activity behaviour of individuals with SCI is amenable to change, and that theory-based interventions may be a means of generating this change.

There is level 1 evidence from a single study that indicates that coping planning as part of action planning is an effective intervention technique for promoting physical activity participation in the SCI population.

There is level 2 evidence from a single study that indicates that facilitating the formation of implementation intentions may be an effective intervention technique for promoting physical activity participation in the SCI population.

More research is needed to identify additional, specific behavioural interventions that are effective in the SCI population. Furthermore, researchers should begin to consider the impact of other types of interventions including informational and environmental interventions.

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