HIGH-INTENSITY INTERVAL TRAINING IN PEOPLE WITH SPINAL CORD INJURY: A SYSTEMATIC REVIEW

TREINAMENTO INTERVALADO DE ALTA INTENSIDADE EM PESSOAS COM LESÃO DA MEDULA ESPINHAL: REVISÃO SISTEMÁTICA

ENTRENAMIENTO POR INTERVALOS DE ALTA INTENSIDAD EN PERSONAS CON LESIONES MEDULARES: UNA REVISIÓN SISTEMÁTICA

Systematic Review
Revisão Sistemática
Revisión Sistemática

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ABSTRACT

Objective: Analyze the effects of high-intensity interval training (HIIT) on cardiometabolic parameters, and cardiorespiratory fitness to compile the most used HIIT training types in adults with spinal cord injury (SCI). Methods: This is a systematic review of searches performed in the electronic databases PubMed / Medline, Science Direct, and Google Scholar. Studies included I) needed to apply HIIT training II) adults with SCI to analyze III) cardiometabolic aspects and cardiorespiratory fitness. Two independent reviewers selected the articles for inclusion, extracted their data, and assessed their methodological quality. Results: 654 studies were found. Thus, 12 studies, 11 pre- and post--intervention, and one control group (CG) with 106 participants were analyzed. Pre- and post-HIITT intervention results revealed significant improvement in cardiorespiratory fitness and cardiometabolic aspects (VO_2peak, LDH, HDL, insulin resistance). In addition, GC results revealed significant improvement in cardiorespiratory fitness observed in the intervention group (HIIT) compared to the moderate-low intensity (GC) group. Seven studies used the arm ergometer as the primary exercise modality. Two studies described functional electrical stimulation (FES) performed with the arm ergometer plus electrical stimulation in the lower limbs. None reported heart rate dynamics during the study period. Conclusion: High-intensity interval training improves physical fitness and cardiometabolic health in adults with SCI. ***Evidence level II; Systematic Review of level II studies.***

Keywords: Spinal Cord Injuries; High-Intensity Interval Training; Metabolism; Physical Fitness.

RESUMO

Objetivo: Analisar os efeitos do treinamento intervalado de alta intensidade (HIIT) nos parâmetros cardiometabólicos, aptidão cardiorrespiratória e compilar os tipos de HIIT mais utilizados no treinamento em adultos com lesão da medula espinhal (LME). Métodos: Trata-se de revisão sistemática, para a qual foram realizadas pesquisas nas bases de dados eletrônicas PubMed / Medline, Science Direct e Google Scholar. Foram incluídos estudos em que I) o treinamento HIIT era aplicado em II) adultos com LME e analisaram III) os aspectos cardiometabólicos e aptidão cardiorrespiratória. Dois revisores independentes selecionaram os artigos para a inclusão, extraindo seus dados e avaliarando a sua qualidade metodológica. Resultados: 654 estudos foram encontrados. Desses, 12 estudos, 11 pré e pós intervenção e 1 grupo controle (GC) com um total de 106 participantes foram analisados. Resultados pré e pós intervenção de HIIT revelaram significante melhora na aptidão cardiorrespiratória e aspectos cardiometabólicos (VO_2pico, LDH, HDL, resistência à insulina). Resultados do GC revelaram uma significativa melhoria na aptidão cardiorrespiratória observada no grupo de intervenção (HIIT) em relação ao grupo de intensidade moderada-baixa (GC). Sete estudos usaram o ergômetro de braço como modalidade de exercício primária. Dois estudos descreveram a estimulação elétrica funcional (EEF) realizada com o ergômetro de braço adicionando estimulação elétrica nos membros inferiores. Nenhum relatou a dinâmica da frequência cardíaca durante o período do estudo. Conclusão: O treinamento intervalado de alta intensidade melhora a aptidão física e a saúde cardiometabólica em adultos com LME. ***Nível de evidência II; Revisão sistemática de Estudos de Nível II.***

Descritores: *Traumatismos da Medula Espinal; Treinamento Intervalado de Alta Intensidade; Metabolismo; Aptidão Física.*

RESUMEN

Objetivo: Analizar los efectos del entrenamiento interválico de alta intensidad (HIIT) sobre los parámetros cardiometabólicos, fitness cardiorrespiratorio y recopilar los tipos de HIIT más utilizados en el entrenamiento en adultos con lesión medular (LME). Métodos: Se trata de una revisión sistemática, para lo cual se realizaron búsquedas en bases de datos electrónicas PubMed/Medline, Science Direct y Google Scholar. Se incluyeron estudios que I) necesitaban aplicar entrenamiento HIIT en II) adultos con SCI y analizar III) aspectos cardiometabólicos y aptitud cardiorrespiratoria. Dos revisores independientes seleccionaron los artículos para su inclusión, extrajeron sus datos y evaluaron su calidad metodológica. Resultados: De los 654 estudios encontrados, se analizaron 12 estudios, 11 pre y post intervención y 1 grupo control (GC) con un total de 106 participantes. Los resultados previos y posteriores a la intervención HIIT revelaron una mejora significativa en la aptitud cardiorrespiratoria y los aspectos cardiometabólicos (VO_2pico, LDH, HDL, resistencia a la insulina). Los resultados de GC

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revelaron una mejora significativa en la aptitud cardiorrespiratoria observada del grupo de intervención (HIIT) en comparación con el grupo de intensidad moderada-baja (GC). Siete estudios utilizaron el ergómetro de brazo como la modalidad principal de ejercicio. Dos estudios describieron la estimulación eléctrica funcional (EEF) realizada con el ergómetro de brazo más la estimulación eléctrica en los miembros inferiores. Ninguno informó la dinámica de la frecuencia cardíaca durante el período de estudio. Conclusiones: El entrenamiento intervalos de alta intensidad mejora la condición física y la salud cardiometabólica en adultos con LME. ***Evidencia de nivel II; Revisión sistemática de estudios de nivel II.***

Descriptores: *Traumatismos de la Médula Espinal; Entrenamiento de Intervalos de Alta Intensidad; Metabolismo; Aptitud Física.*

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INTRODUCTION

Spinal cord injury (SCI) is a damage along the spinal cord's length, causing motor and sensory deficits.[1] The population with SCI has a high degree of mortality from cardiometabolic diseases and a greater predisposition to these conditions[2-6] and, in general, they have low levels of physical activity compared to people without disabilities, and this is related to mobility difficulties.[7-9] In contrast, this sedentary profile and the associated cardiometabolic risk could be prevented by physical activity.[10]

It seems to be a consensus that physical activity promotes benefits in cardiopulmonary indicators, quality of life, functional independence, and strength.[11-13] Furthermore, high-intensity physical activity through sport has also been related to cardiovascular risk reduction,[14,15] improved diastolic function[16], and better body composition.[17] In addition to sports practice, other models of high-intensity interval exercise (HIIT) performed in different contexts have received attention.

Thus, HIIT is defined as a training modality in which the practitioner alternates high-intensity efforts (i.e., above the anaerobic threshold) with rest periods that can be active or passive.[18] Specifically, classification models are derived from manipulating intervening variables, which are organized, among other proposals, into long intervals, short intervals, repeated *sprint* training (RST), and sprint interval training (SIT).[18] These models stand out by allowing higher intensity levels to be maintained for longer,19 which seems stung for adaptive cardiorespiratory changes.[20] In people with SCI, accurate knowledge of responses to HIIT is still emerging.[21-28]

Therefore, considering the potential of HIIT to promote positive adaptations in individuals with SCI, the present study aims to systematize the knowledge already available about the effects of HIIT on cardiometabolic and cardiorespiratory parameters in people with SCI.

METHODS

Preliminary Information

This systematic review is based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) terms.[29] The study had the following PICO strategy as its question: People with spinal cord injury (participants); High-intensity interval training (HIIT) (intervention); Descriptive data on HIIT (comparison); Improvement of cardiometabolic and fitness aspects (results).

Search Strategy

Searches were performed in PubMed / Medline, Science Direct, and Google Scholar electronic databases in January 2022. They were used: PubMed / Medline: high-intensity interval training AND spinal cord injury; Science Direct: "High-intensity interval training" AND "Spinal cord injury" and Google Scholar: High-intensity interval training AND spinal cord injury AND cardiorespiratory AND metabolic AND improve AND elicit AND ergometer AND adaptations AND paraplegic. The articles were selected by reading the title and abstract, and duplicates were excluded. After selection, the articles were read fully, and the inclusion criteria were applied.

Criteria for election

This systematic review included articles that i) applied the HIIT method; ii) in adult individuals with SCI and; iii) performed analyses of cardiometabolic and fitness aspects, showing the results by mean and standard deviation. Pilot studies, systematic and scoping review articles, book chapters, conference abstracts, and those not meeting the inclusion criteria were excluded.

Data Extraction

Data extraction was performed based on an extraction table developed by the authors. The data collected were: the purpose of the study, sample, groups, training methods, research duration, weekly training frequency, session duration in minutes, and main results.

Quality Assessment

The methodological quality of the studies presented in Table 1 was assessed with the Apprisal for Cross-Sectional Studies (AXIS) tool.[30] Two authors (CM, KS) performed the quality assessment separately, and disagreements were resolved by consensus in the presence of a third reviewer (AC). In the AXIS tool, for each correct answer, a score of one was assigned to each of the twenty questions. These tools aim to evaluate the methodological rigor of these studies.

RESULTS

Study Selection

The initial search found 654 articles (PubMed = 19; Science direct = 39; Google Scholar = 596). After excluding duplicates and applying the inclusion and exclusion criteria, 11 articles remained for this systematic review. (Figure 1)

Description of the study

Table 2 describes the sample characteristics of the selected studies. A total of 106 individuals underwent the HIIT method interventions. Of those, 14 (13.2%) were female, and 92 (86.7%) were male. One of the studies did not describe the gender of the participants.[31] Only one study had a control group.[23]

Regarding the training duration, the studies showed differences in the total intervention time with training protocols lasting from one to twelve weeks. The study that applied the training protocol for only one week and also obtained improvement in aerobic capacity.[21] Improvements in cardiometabolic parameters (e.g., LDH, HDL, insulin resistance) were observed in two studies.[27,31] None of the reviewed studies reported the heart rate dynamics during the study period. The number of training sessions also varied from 1 to 3 times a week.

The arm ergometer was the main equipment used for HIIT training.[21,24-27,32] Eight studies used the arm ergometer as the primary exercise modality. In addition, two studies have described exercises performed with the arm ergometer plus FES.[28,31] Regarding the applied stimulus

Table 1. Assessment tool for cross-sectional studies (AXIS).

Question	(52)	(53)	(54)	(55)	(56)	(57)	(58)	(59)	(60)	(61)	(62)	(25)
Introduction												
1. Were the objectives of the study clear?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Methods												
2. Was the study design appropriate for the stated objective(s)?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3. Was the sample size justified?	N	N	N	N	N	N	N	N	N	N	N	N
4. Has the target/reference population been clearly defined? (Is it clear who the research was about?)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5. Was the sampling frame drawn from an appropriate population base so that it closely represented the target/reference population under investigation?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6. Was the selection process likely to select subjects/participants representative of the target/reference population under investigation?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7. Have steps been taken to address and categorize non-responders?	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8. Were the risk factors and outcome variables measured appropriately for the study objectives?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
9. Were the risk factors and outcome variables measured correctly using instruments/measures that have been previously tried, tested, or published?	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
10. Is it clear what was used to determine statistical significance and precision estimates? (e.g., p-values, CIs)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
11. Are the methods (including statistical methods) described sufficiently to allow their repetition?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Results												
12. Is the basic data adequately described?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
13. Does the response rate raise concerns about non-response bias?	N	N	N	N	N	N	N	N	N	N	N	N
14. If appropriate, was information about non-responders described?	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
15. Were the results internally consistent?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
16. Were the results of the analyses described in the methods presented?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Discussion												
17. Were the authors' discussions and conclusions justified by the results?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
18. Were the limitations of the study discussed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Other												
19. Were there any funding sources or conflicts of interest that might affect the authors' interpretation of the results?	N	N	N	N	N	N	N	N	N	N	N	N
20. Was ethical approval or consent obtained from the participants?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Caption: Y = Yes, N = No, and NI = Not Informed.

time, the minimum observed was 30 seconds[33] and the maximum was 5 minutes.[26] Two of the twelve studies included in this review studied cardiometabolic and cardiorespiratory parameters.[27,31] Two reviewers determined the quality assessment of the studies.

All the studies reported changes in the subjects' aerobic capacity, mostly using the HIIT protocol with the arm ergometer, without another method.[21,23,25-27,32-35] Two studies used the combination of upper limb exercises and lower limb FES application, resulting in significant improvements in aerobic capacity[27,28,31] reported improvements in cardiometabolic parameters (e.g., LDH, HDL, insulin resistance).

DISCUSSION

This systematic review aimed to analyze the effect of HIIT on cardiometabolic parameters indicators and cardiorespiratory fitness in people with SCI. The main finding indicates that HIIT is considered a "time efficient" strategy, compared to continuous training, for improving cardiometabolic health and fitness markers. Special populations may benefit from this training.

Seven of the eleven studies that used arm exercises with HIIT protocol report improved cardiorespiratory fitness, indicating that this exercise effectively promotes positive changes in this parameter. These results are in agreement with the findings of studies that observe cardiorespiratory improvements in exercises performed with the aid of the arm ergometer.[36-38]

HIIT requires less training time than continuous training[39], and in people, without disabilities, it presents itself as an alternative to continuous training to promote improvements in cardiometabolic parameters.[40] The effects observed in research using short single-session HIIT protocols showed increased VO_2max.[21,33] These results agree with those of HIIT use in non-disabled people.[41] One study compared energy expenditure between HIIT and moderate-intensity continuous training, concluding that similar caloric expenditure occurs between the two training models (115.9 ± 21.8 vs. 116.6 ± 35.0 kcal).[25] However, another study in obese adults identified that more duration time was required in moderate-intensity continuous training compared to HIIT (39.8 ± 4.6 vs. 32.2 ± 6.2 min).[42]

Official exercise guidelines for cardiorespiratory fitness benefits for adults with SCI suggest moderate to vigorous intensity at least two to three times per week, further indicating that for cardiometabolic health benefits, adults with SCI should perform at least 30 minutes of moderate to vigorous aerobic intensity three times per week.[2,43] The protocols observed in this review, except for one study that did not report the timing of the HIIT protocol,[28] follow the timing recommendations proposed in the guideline for people with SCI. (Table 1).

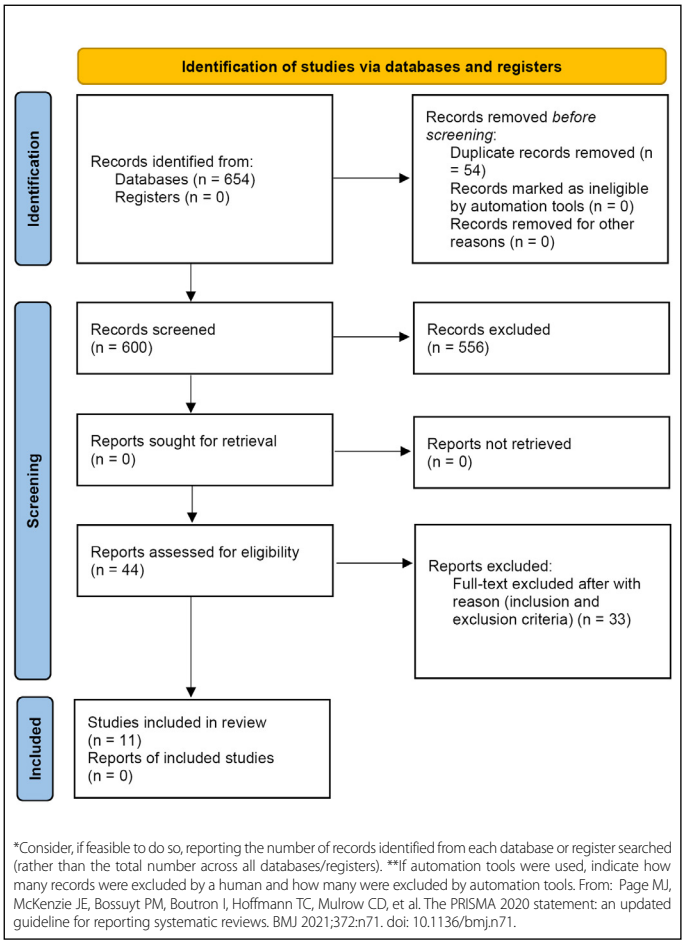

Figure 1. Prisma 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

The studies in this review did not show how heart rate behaved during HIIT. To better understand the isolated impact of prescribed exercise interventions on cardiovascular health, future studies may control for heart rate response throughout the protocol, providing a better understanding of the overall impact of high-intensity exercise interventions in people with SCI. The HRmax values observed in people with SCI may differ slightly due to the smaller ejection volume than those without disability.[44-46] Knowledge of heart rate responses at different running intensities is essential for correct exercise prescription.[47]

It is evident in this review that most studies presented a sample composed of people with low spinal cord injury (paraplegia), which seems to influence cardiorespiratory outcomes.[48,49] Metabolic parameters seem to be influenced by the time of injury of the individual. No improvement in cardiometabolic parameters was observed in people with chronic SCI after six weeks of HIIT.[31] On the other hand, it proved sufficient to alter metabolic markers in people with acute SCI undergoing eight weeks of HIIT.[27] The difference observed between the studies seems to be influenced by the time of injury of the sample.

Previous studies in non-disabled people have observed the effectiveness of HIIT over continuous training in improving cardiometabolic risk factors.[40,50] However, the spinal cord injury population results are discrete and should be evaluated carefully.[27,31] Most studies to evaluate the effectiveness of HIIT in improving cardiometabolic parameters have been conducted with a small sample size,[27,31] which justifies the need for new studies. The data presented are summary evidence of the effect of HIIT on cardiometabolic risk factors such as HDL-c, LDL-c, triglycerides, glucose, and total cholesterol.

The glucose response during the application of HIIT and continuous training in people with SCI was reduced.[27,51] The insulin results must be analyzed cautiously since the small sample size (n = 3) and the difference in age and sex may sensitize responses to exercise.[27] Two of the twelve studies in this review, which measured insulin concentration before and

Table 2. Characteristics of the selected studies.

Author year	Goal	Sample	Groups	Methods training	Duration study	Frequency	Duration	Main Results Average (SD)
(de Groot et al.,[25] 2003)	To evaluate the effect of training intensity on physical capacity, lipid profile, and insulin sensitivity in early rehabilitation of spinal cord injury (SCI) patients and to assess the correlation between peak aerobic capacity (VO_2peak) and insulin sensitivity.	6 SCI individuals.	1 - High intensity (HI; 70-80% of heart rate reserve (HRR)) 2 - Low intensity (LI; 40-50% HRR)	Arm training intervention (not specified) Repeated 3 min sessions of ACE (70-80%HRR)	8 weeks	3x week	20 min	Post-test values relative to pre-test values expressed in percent (SD). HI Group: %(SD) VO_2peak = 150 (24) Insulin sensitivity = 67 (9) TC/HDL ratio = 77 (6) Triglycerides = 69 (7) Group LI: %(SD) VO_2peak = 117 (4) Insulin sensitivity = 156 (55) TC/HDL ratio = 100 (20) Triglycerides = 95 (14)
(Tordi et al.,[33] 2001)	It investigated the effects of a short-interval training program designed specifically for patients with spinal cord injuries.	5 Paraplegic man.	No group.	. Repeated 5-minute wheelchair ergometry sessions 50 and 80% PPO.	4 weeks	3x week	30-min	↑ VO_2peak (ml min kg/1): -Pre = 21 -Post = 24 ↑ HR peak (b min1): -Pre = 191 -Post = 183 ↑ VE peak (l min^1): -Pre = 64 -Post = 78 ↑ O2p (ml b1): -Pre = 7.9 -Post = 9.9

(Brurok et al.,[26] 2011)	To determine the effect of high-intensity interval training during combined arm cycling (ACE) exercise in individuals with spinal cord injury (SCI) and functional electrical stimulation of leg cycling (hybrid exercise), on peak systolic volume and peak oxygen consumption	6 men with SCI in stable neurological recovery (ASIA *Impairment Scale* grade A)	No Group	Hybrid cycling interval training. Repeated 4 min sessions of ACE + FES 85-90 %PPO.	8 weeks preceded by a 7-week control period of regular daily activity	3x week	Not reported	↑ at VO 2 peak. Hybrid Training VO_2pre = 1.96l/min VO_2post = 2.43l/min ↑ SV (ml/beat) Pre= 83.2 (9.1) Post= 103.4 (17.1) Arm cycle training VO_2pre = 1.48L/min VO_2post = 2L/min FES leg cycling VO_2pre = 0.62L/min VO_2post = 0.78L/min ↑ VE, liter/min: -Pre = 66.7 (24.4) -Post = 80.2 (29.4) ↑ Peak HR: -Pre = 171 (12) -Post = 170 (26)
(Hasnan et al.,[29] 2013)	To investigate the effect of "hybrid" high-intensity interval training (arm cycling and leg FES) in a virtual reality environment on aerobic fitness, power, lipid profiles, and glucose tolerance in people with LM.	8 individuals with SCI	No Group	Hybrid high-intensity interval training (HIT) using an arm tricycle + leg FES. Repeated 8 min sessions of ACE + FES 80-90 %HRmax.	6 weeks	2-3x week	32 min or 48 min	↑ VO_2peak mL-kg-1-min: Pre = 19.3(3.4) Post = 23.2(3.4) Biochemical blood markers of cardiovascular risk, including total cholesterol, HDL, LDL, and oral glucose tolerance scores, remained unchanged after training, although some individuals observed modest improvements.
(Wouda et al.,[22] 2018)	Investigate whether high-intensity interval training (HIIT) increases physical capacity and activity levels more than moderate-intensity training (MIT) and usual treatment.	25 men and 5 women with incomplete spinal cord injury.	MIT, HIIT and control.	The MIT group was instructed to exercise three times a week at 70% of HRmax, while the HIIT group was instructed to exercise twice a week at 85-95% of HRmax. The control group received treatment as usual.	12 weeks	3x week	35 min	↑ VO_2 peak. HIIT VO_2pre = 2.7 l/min VO_2post = 3 l/min MIT VO_2pre = 2.79l/min VO_2post = 3.23L/min Control VO_2pre = 2.78L/min VO_2post = 3.15L/min
(Gauthier et al.,[32] 2018)	To investigate and compare the feasibility, safety and preliminary efficacy of high intensity interval training (HIIT) and moderate-intensity continuous training (MICT) programs in a self-managed manual wheelchair at home.	11 manual wheelchair users. Users with SCI.	HIIT and MICT	HIIT: Participants were asked to propel their wheelchair at a high and low intensity during 30 and 60 second intervals, respectively, and repeat this sequence 20 times over 30 minutes. During the 30-second high-intensity interval, participants needed to achieve an RPE between 6 and 8 (very difficult). Each high-intensity interval was followed by a low-intensity interval of 60 seconds at an RPE between 1 (very light) and 2 (light). MICT: Participants were then asked to propel their wheelchairs for 30 minutes at a constant speed, maintaining an RPE between 4 (somewhat difficult) and 5 (difficult).	6 weeks	3x week	40min	↑ in VO_2peak(ml.min) HIIT Pre = 19.5(0.7) Post = 20.4(3.9) MICT Pre = 18.5 (6.8) Post = 18.9 (8.4)

(Astorino & Thum,[31] 2018)	To examine enjoyment in response to CEX and HIIT differences in people with SCI.	9 habitually active men and women with SCI.	No Group	CEX (45%Wpico), SIT (105%Wpico), or HIIT (70%Wpico in random order.	2-3 weeks	3 sessions consisted of CEX, HIIT, or SIT, whose order was randomized. A minimum of 2 days and a maximum of 7 days apart each trial.	~40 min	↑ VO_2peak. VO_2rest= 0.25-0.28 l/min. VO_2HIIT= 1.13l/min VO_2SIT= 1.02l/min. VO_2MCIT=0.90l/min.
(Astorino,[20] 2019)	Determined hemodynamic and cardiorespiratory responses to different arm cycles in men with LM. hemodynamic responses compared to high intensity interval exercise (HIIE) and moderate-intensity continuous exercise (MICE)	5 men with LM.	MICE, HIIE and SIE	MICE: continuous cycling required at 35% PPO. HIIE consisted of repeated sessions of 60 s at 85% PPO with 120 s recovery at 10% PPO. SIE: 30 s sessions required at 115% PPO separated by 90 s recovery at 10% PPO.	1-2 weeks	5 randomized sessions	~30min	↑ VO_2 peak. VO_2rest= 0.24l/min VO_2HIIE= 1.3(0.4) l/min VO_2SIE= 1.2(0.5) l/min. VO_2MICE=0.8(0.3) l/min
(Thum & Astorino,[51] 2016)	Compare the changes in cardiorespiratory and metabolic variables between two regimes of interval training and moderate-intensity exercise	8 men and 1 woman with chronic LM.	No Group	MICT- 45%Wpico; HIIT- 70%Wpico; SIT- 105% Wpico.	2-3 week	The participants completed four exercise sessions in the lab. The sessions were held simultaneously between participants and were preceded by a 3-hour fast and 24-hour abstention from exercise.	MICT: 30min HIIT: 25min SIT: 25min	↑ in VO_2 peak. Effect size = 0.82 VO_2pre= 0.25-0.28 l/min. VO_2post= HIIT= 1.13L/min SIT= 1.02L/min. MCIT=0.90L/min.
(KOONTZ,[30] 2021)	The objective of this study was to explore the feasibility of of a HIIT handcycling training program for wheelchair users with SCI.	7 men and 3 women with chronic SCI. 7 quadriplegics and 3 paraplegics.	No Group	The HIIT training sessions were held in the participant's home with a trainer from the study. HIIT: 90% PPO.	6 weeks	2x week	HIIT: 2x 25min. 10 hand-cycling intervals (1:1).	VO_2 peak: Average (SD) Baseline: 14.3 (5.0) Post-intervention: 14.3 (4.8) Peak power output (watts) Baseline: 60.0 (33.3) Post-intervention: 65.0 (38.5)
(McMillan et al.,[24] 2021)	To test for differences in the duration and magnitude of the physiological response to the moderate isocaloric intensity continuous sessions (MICE) and high intensity interval exercise (HIIE) in people with spinal cord injury.	10 adult men with complete chronic paraplegia (T2-T10).	HIIT group and continuous moderate-intensity group (MICE)	HIIT Group: >80% VO_2peak during the work phase, with a peak intensity of ~ 90% VO_2peak. MICE Group: 50% VO_2peak.	2 weeks	1 week.	HIIT: (80:10% POpeak 2:2 min)	MICE: Duration(min) 39.8(4.6) HRmax: 105(12) VO_2ml·kg−1min−1) 10.1(2.2) %VO_2peak 53(6.6) Energy expended (kcal): 115.9(21.8) HIIT Duration(min): 32.2(6.2) FCmax: 124(17) VO_2(ml·kg−1min−1): 12.6(3.1) %VO_2peak: 66.1(5.2) Energy expended (kcal): 116.6(35)

after the training intervention, reported very discrete results after HIIT for the upper body, suggesting that this training form needs further exploration to demonstrate its effectiveness.

This review highlights the use of HIIT as an effective strategy for inducing positive cardiometabolic responses in people with SCI. In addition, we believe the results observed in this research should serve as a data source to clarify and safely and efficiently conduct this training method in people with SCI. Finally, this review highlights the magnitude of using HIIT as a "time efficient" strategy that effectively induces cardiometabolic responses in people with SCI.

Limitations

The current review included only a small number of studies with small sample sizes. The limited number of overlapping outcome measurements and data provided means a meta-analysis could not be performed. In addition, considerable variation was observed in the HIIT protocols applied in each study. Thus, the heterogeneity of subjects and interventions must be considered when considering the evidence synthesis.

Future Directions

There are several important avenues for the future study of HIIT in the population of people with SCI. First, future research should determine different HIIT protocols (e.g., short HIIT, long HIIT, low volume, high volume) and equipment modalities (e.g., naval rope, elastic bands, rower). Researchers should also compare the effectiveness of HIIT with other training programs (e.g., continuous high-intensity aerobic training and progressive aerobic training). In addition, the impact of HIIT on clinically important outcomes for this population (e.g., functional independence, quality of life, viability, and adherence) can be explored using reliable measures and validated.

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CONCLUSION

Overall, preliminary evidence suggests that HIIT may be an effective improving intervention for some cardiorespiratory and metabolic fitness aspects in individuals with spinal cord injuries. The literature indicates that training 1 to 3 times a week for 1 to 12 weeks at 80% starting intensity HRmax and 70% PPO was sufficient to change the cardiometabolic and cardiorespiratory markers. However, randomized clinical trials with larger sample sizes and high methodological quality are needed to understand the HIIT effectiveness in the spinal cord injury population.

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REFERENCES

1. McDonald JW, Sadowsky C. Spinal-cord injury. Lancet. 2002;359(9304):417-25.
2. Martin Ginis KA, van der Scheer JW, Latimer-Cheung AE, Barrow A, Bourne C, Carruthers P, et al. Evidence--based scientific exercise guidelines for adults with spinal cord injury: an update and a new guideline. Spinal Cord. 2018;56(4):308-21.
3. Nash MS, Groah SL, Gater DR, Dyson-Hudson TA, Lieberman JA, Myers J, et al. Identification and Management of Cardiometabolic Risk after Spinal Cord Injury. J Spinal Cord Med. 2019;42(5):643-77.
4. Sabre L, Rekand T, Asser T, Kõrv J. Mortality and causes of death after traumatic spinal cord injury in Estonia. J Spinal Cord Med. 2013;36(6):687-94.
5. Garshick E, Kelley A, Cohen SA, Garrison A, Tun CG, Gagnon D, et al. A prospective assessment of mortality in chronic spinal cord injury. Spinal Cord. 2005;43(7):408-16.
6. van den Berg-Emons RJ, Bussmann JB, Haisma JA, Sluis TA, van der Woude LH, Bergen MP, et al. A prospective study on physical activity levels after spinal cord injury during inpatient rehabilitation and the year after discharge. Arch Phys Med Rehabil. 2008;89(11):2094-101.
7. de Groot S, van der Scheer JW, Bakkum AJT, Adriaansen JJE, Smit CA, Dijkstra C, et al. Wheelchair-specific fitness of persons with a long-term spinal cord injury: cross-sectional study on effects of time since injury and physical activity level. Disabil Rehabil. 2016;38(12):1180-6.
8. Buchholz AC, McGillivray CF, Pencharz PB. Physical activity levels are low in free-living adults with chronic paraplegia. Obes Res. 2003;11(4):563-70.
9. Nightingale TE, Metcalfe RS, Vollaard NB, Bilzon JL. Exercise Guidelines to Promote Cardiometabolic Health in Spinal Cord Injured Humans: Time to Raise the Intensity?. Arch Phys Med Rehabil. 2017;98(8):1693-704.
10. Tweedy SM, Beckman EM, Geraghty TJ, Theisen D, Perret C, Harvey LA, et al. Exercise and sports science Australia (ESSA) position statement on exercise and spinal cord injury. J Sci Med Sport. 2017;20(2):108-15.
11. Akkurt H, Karapolat HU, Kirazli Y, Kose T. The effects of upper extremity aerobic exercise in patients with spinal cord injury: a randomized controlled study. Eur J Phys Rehabil Med. 2017;53(2):219-27.
12. Hicks AL, Martin KA, Ditor DS, Latimer AE, Craven C, Bugaresti J, et al. Long-term exercise training in persons with spinal cord injury: effects on strength, arm ergometry performance and psychological well-being. Spinal Cord. 2003;41(1):34-43.
13. Matos-Souza JR, Rossi G de, Silva AAC e, Azevedo ER, Pithon KR, Schreiber R, et al. Impact of Adapted Sports Activities on the Progression of Carotid Atherosclerosis in Subjects With Spinal Cord Injury. Archives of Physical Medicine and Rehabilitation. 2016;97(6):1034-7.
14. Matos-Souza JR, Silva AA, Campos LF, Goulart D, Schreiber R, Rossi G de, et al. Physical activity is associated with improved subclinical atherosclerosis in spinal cord injury subjects independent of variation in traditional risk factors. Int J Cardiol. 2013;167(2):592-3.
15. DE Rossi G, Matos-Souza JR, Costa E Silva ADEA, Campos LF, Santos LG, Azevedo ER, et al. Physical activity and improved diastolic function in spinal cord-injured subjects. Med Sci Sports Exerc. 2014;46(5):887-92.
16. Gorla JI, Godoy PS, Calegari DR, Silva A de AC, Borges M, Tanhoffer RA, et al. Impact of wheelchair rugby on body composition of subjects with tetraplegia: a pilot study. Arch Phys Med Rehabil. 2016;97(1):92-6.
17. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports Med. 2013;43(5):313-38.
18. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. Sports Med. 2002;32(1):53-73.
19. Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness?. Appl Physiol Nutr Metab. 2014;39(3):409-12.
20. Astorino TA. Hemodynamic and cardiorespiratory responses to various arm cycling regimens in men with spinal cord injury. Spinal Cord Ser Cases. 2019;5:2.
21. Graham K, Yarar-Fisher C, Li J, McCully KM, Rimmer JH, Powell D, et al. Effects of High-Intensity Interval Training Versus Moderate-Intensity Training on Cardiometabolic Health Markers in Individuals With Spinal Cord Injury: A Pilot Study. Top Spinal Cord Inj Rehabil. 2019;25(3):248-59.
22. Wouda MF, Lundgaard E, Becker F, Strøm V. Effects of moderate- and high-intensity aerobic training program in ambulatory subjects with incomplete spinal cord injury-a randomized controlled trial. Spinal Cord. 2018;56(10):955-63.
23. Astorino TA, Thum JS. Interval training elicits higher enjoyment versus moderate exercise in persons with spinal cord injury. J Spinal Cord Med. 2018;41(1):77-84.
24. McMillan DW, Maher JL, Jacobs KA, Nash MS, Bilzon JLJ. Physiological responses to moderate intensity continuous and high-intensity interval exercise in persons with paraplegia. Spinal Cord. 2021;59(1):26-33.
25. de Groot PCE, Hjeltnes N, Heijboer AC, Stal W, Birkeland K. Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. Spinal Cord. 2003;41(12):673-9.
26. Brurok B, Helgerud J, Karlsen T, Leivseth G, Hoff J. Effect of aerobic high-intensity hybrid training on stroke volume and peak oxygen consumption in men with spinal cord injury. Am J Phys Med Rehabil. 2011;90(5):407-14.
27. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Reprint—Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Phys Ther. 2009;89(9):873-80.
28. Downes MJ, Brennan ML, Williams HC, Dean RS. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). BMJ Open. 2016;6(12):e011458.
29. Hasnan N, Engkasan JP, Husain R, Davis GM. High-Intensity Virtual-reality Arm plus FES-leg Interval Training in Individuals with Spinal Cord Injury. Biomed Tech (Berl). 2013;58(Suppl 1).
30. Koontz AM, Garfunkel CE, Crytzer TM, Anthony SJ, Nindl BC. Feasibility, acceptability, and preliminary efficacy of a handcycling high-intensity interval training program for individuals with spinal cord injury. Spinal Cord. 2021;59(1):34-43.
31. Astorino TA, Thum JS. Within-session responses to high-intensity interval training in spinal cord injury. Disabil Rehabil. 2018;40(4):444-9.
32. Gauthier C, Brosseau R, Hicks AL, Gagnon DH. Feasibility, Safety, and Preliminary Effectiveness of a Home-Based Self-Managed High-Intensity Interval Training Program Offered to Long-Term Manual Wheelchair Users. Rehabil Res Pract. 2018;2018:8209360.
33. Tordi N, Dugue B, Klupzinski D, Rasseneur L, Rouillon JD, Lonsdorfer J. Interval training program on a wheelchair ergometer for paraplegic subjects. Spinal Cord. 2001;39(10):532-7.
34. Williams AMM, Chisholm AE, Lynn A, Malik RN, Eginyan G, Lam T. Arm crank ergometer "spin" training improves seated balance and aerobic capacity in people with spinal cord injury. Scand J Med Sci Sports. 2020;30(2):361-9.
35. Lytle LL, Dannenbring JL, Kilgas MA, Elmer SJ. Eccentric Arm Cycling: A Potential Exercise for Wheelchair Users. Arch Phys Med Rehabil. 2019;100(5):914-22.

36. Eerden S, Dekker R, Hettinga FJ. Maximal and submaximal aerobic tests for wheelchair-dependent persons with spinal cord injury: a systematic review to summarize and identify useful applications for clinical rehabilitation. Disabil Rehabil. 2018;40(5):497-521.

37. Chin EC, Yu AP, Lai CW, Fong DY, Chan DK, Wong SH, et al. Low-Frequency HIIT Improves Body Composition and Aerobic Capacity in Overweight Men. Med Sci Sports Exerc. 2020;52(1):56-66.

38. Stavrinou PS, Bogdanis GC, Giannaki CD, Terzis G, Hadjicharalambous M. High-intensity Interval Training Frequency: Cardiometabolic Effects and Quality of Life. Int J Sports Med. 2018;39(3):210-7.

39. Olney N, Wertz T, LaPorta Z, Mora A, Serbas J, Astorino TA. Comparison of Acute Physiological and Psychological Responses Between Moderate-Intensity Continuous Exercise and Three Regimes of High-Intensity Interval Training. J Strength Cond Res. 2018;32(8):2130-8.

40. Keating SE, Machan EA, O'Connor HT, Gerofi JA, Sainsbury A, Caterson ID, et al. Continuous Exercise but Not High Intensity Interval Training Improves Fat Distribution in Overweight Adults. J Obes. 2014;2014:834865.

41. Ginis KAM, Hicks AL, Latimer AE, Warburton DER, Bourne C, Ditor DS, et al. The development of evidence--informed physical activity guidelines for adults with spinal cord injury. Spinal Cord. 2011;49(11):1088-96.

42. Flores L, Antunes M, Costa e Silva A, Gorla J. Respostas cardiovasculares e avaliação da potência aeróbia em pessoas com lesão da medula espinhal. RBAFS. 2013;18:145-55.

43. Price MJ. Thermoregulation during exercise in individuals with spinal cord injuries. Sports Med. 2006;36(10):863-79.

44. Theisen D, Vanlandewijk Y. Cardiovascular responses and thermoregulation in individuals with spinal cord injury. Eur Bull Ad Phys Act. 2021;1.

45. Almeida MB de. Heart rate and exercise: An evidence based interpretation. Rev Bras Cineantropom Desempenho Hum. 2007;9(2):196-202.

46. Simmons OL, Kressler J, Nash MS. Reference fitness values in the untrained spinal cord injury population. Arch Phys Med Rehabil. 2014;95(12):2272-8.

47. Au JS, Totosy DE Zepetnek JO, Macdonald MJ. Modeling Perceived Exertion during Graded Arm Cycling Exercise in Spinal Cord Injury. Med Sci Sports Exerc. 2017;49(6):1190-6.

48. Dun Y, Smith JR, Liu S, Olson TP. High-Intensity Interval Training in Cardiac Rehabilitation. Clin Geriatr Med. 2019;35(4):469-87.

49. Farrow MT, Maher J, Thompson D, Bilzon JLJ. Effect of high-intensity interval training on cardiometabolic component risks in persons with paraplegia: Protocol for a randomized controlled trial. Exp Physiol. 2021;106(5):1159-65.

50. Harnish CR, Daniels JA, Caruso D. Training response to high-intensity interval training in a 42-year-old man with chronic spinal cord injury. J Spinal Cord Med. 2017;40(2):246-9.

51. Thum JS, Astorino TA. Greater enjoyment in two modes of high intensity interval training (hiit) compared to continuous exercise training (cex) in persons with spinal cord injury (sci). 2016;10:1-10.