Case report

Training response to high-intensity interval training in a 42-year-old man with chronic spinal cord injury

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Objective: To review the outcome of 12 weeks of periodized, high-intensity interval training (HIT) in a man with chronic traumatic spinal cord injury (SCI).

Methods: A 42-year-old man (180 cm tall, 68.4 kg and 32.0% Fat) with a C8/T1 motor complete SCI took part in 12 weeks of 3 days per week arm crank ergometry (ACE) interval training. Training consisted of a combination of HIT that included three times 5 min at ~70% Peak Power (W_{Peak}) and 5 min recovery (HIT₅); four times 2.5 min at ~85% W_{Peak} and 5 min recovery (HIT_{2.5}); ten times 1 min at ~110% W_{Peak} and 2 min recovery (HIT₁). Heart rate (HR) zones were set as <75% HR_{Peak} (Z1), 75–89% (Z2), and 90+ % (Z3) and used to monitor overall training efficacy.

Results: Thirty-six sessions that included 8 HIT₅, 10 HIT_{2.5}, and 5 HIT₁ sessions were completed. W_{Peak} and $VO_{2 Peak}$ improved about 45% and 52%, respectively, by week 6, without further improvement at week 12, HR TRIMP scores and power in training sessions trended upward over the 12-week program.

Conclusions: Twelve weeks of HIT resulted in a large increase in peak aerobic power, as well as submaximal endurance performance in our participant. The early plateau in maximal testing supports the use of submaximal training assessment important in the long-term training monitoring for SCI.

Keywords: $VO_{2 max}$, arm crank ergometry, HIT, Periodization, Special populations

Introduction

Exercise is widely accepted as a means to improved health, including cardiovascular disease risk reduction and reduced all-cause mortality.¹ High intensity interval training (HIT) is highly effective at improving endurance performance² and was recently shown to be the most effective means for improving maximal oxygen consumption ($VO_{2 max}$).³ Contemporary training studies, however, have focused on lower extremity exercise, which may not be applicable to persons with spinal cord injuries (SCI), which are often limited to upper extremity exercise. Moreover, training programs among special populations continue to lag behind able-bodied programs, with only a few SCI training studies available for application.^{4,5} The hallmark of any training program is one that is individually designed for the participant. Little is known, however, about the

impact of specific interval training (HIT) using arm crank ergometry (ACE) among those with SCI. Therefore the purpose of this case study was to develop and implement a specific 12-week periodized ACE HIT program for an individual with spinal cord injury.

Case report

All training took place at the Hunter Holmes McGuire Veterans Administration Medical Center (Richmond, VA), and all experimental protocols adhered to the McGuire VAMC institutional review board (IRB) and complied with the Declaration of Helsinki. ASIA exams were performed on two separate occasions. A 42-year-old African-American male diagnosed with chronic traumatic C8/T1 motor complete SCI suffered in a motor cycle accident 15 years prior, completed an IRB approved informed consent and volunteered to take part in a 12-week periodized program of HIT. The volunteer was 180 cm tall, weighed 66.4 kg at the start of the study, and was estimated to be 32.0% body fat using a total body dual-energy X-ray absorptiometry (DXA) scan

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performed using a Lunar Prodigy (Lunar Inc., Madison, WI, USA) bone densitometer at the McGuire SCI Exercise Physiology Laboratory and analyzed using Lunar software version 13.3; the standard deviation for this DXA was $\pm 2.2\%$. The participant did not report taking any medications during the training period, and had not engaged in any upper extremity exercise for at least 6 months prior to beginning the 12-week program.

Throughout the study period, the individual completed ACE $\text{VO}_{2\text{Peak}}$ tests before HIT, at week 6 and week 13, using an electronically braked LODE Angio ergometer (Electro-Med Corporation, Flint, MI, USA). A continuous 3-minute test protocol was used with a cadence set at 70 rpm and an initial load set to allow for a work rate of 15 W. VO_2 was measured continuously using a Parvo Medics' TrueOne® 2400 metabolic cart (Parvo Medics, Sandy, UT, USA). The volunteer also completed a 30-minute time trial (TT_{30}) test on a Monark 881E ACE to assess endurance performance improvement during the first training session, as well as at weeks 4, 8, and 12. During this test, the workload was set at 0.75 KP while the subject cranked as fast as possible. Heart rate (HR) was measured and stored using a Polar RS 400 (Polar Electro Inc., Lake Success, NY, USA) and blood lactate samples (5 μl) were measured from the ear lobe using a small plastic lancet every 5 min using a Lactate Scout Analyzer (EKF diagnostic sales GmbH, Barleben/Magdeburg, Germany). Average power (W) was calculated using workload, flywheel distance, and average cadence.

Training program

All training was conducted on the LODE arm ergometer with the initial workloads relative to W_{Peak} test results and outlined below. Workloads progressed over the course of the 12-week training period, with reduction in workload two sessions prior to each TT_{30} , while HIT session workloads were adjusted upward based on $\text{VO}_{2\text{Peak}}$ test results. All sessions were preceded by 10 minutes of unloaded cranking before and 5 minutes after training. Blood pressure was measured prior to warm-up and immediately following cool-down, and mean arterial pressure (MAP) calculated. The HIT work and rest ratios were based on contemporary cycling and para-cycling training programs. The actual program used a weekly variation of three types of HIT that included:

- 3×5 min at $\sim 70\%$ Peak Power (W_{Peak}) with 5 minute recovery (HIT_5)
- 4×2.5 min at $\sim 85\%$ W_{Peak} with 5 minute recovery ($\text{HIT}_{2.5}$)
- 10×1 min at $\sim 110\%$ W_{Peak} with 2 minute recovery (HIT_1)

HR zones were set as $<75\%$ HR_{Peak} (Z1), 75–89% (Z2), and $90^{+}\%$ (Z3).

Results

Our volunteer completed a total of 36 sessions over approximately 14 weeks, including pre and post $\text{VO}_{2\text{Peak}}$ testing. Of particular note, HR data indicated a normal age-adjusted HR response, with the subject achieving a HR near age-predicted maximum HR on several occasions. During the course of the training period, 8 HIT_5 , 10 $\text{HIT}_{2.5}$, and 5 HIT_1 sessions, respectively, with an average session lasting 33.9 minutes; a summary depiction of training is provided in Figure 1. After the initial two weeks of training, power output during training sessions trended upward for the remaining 10 weeks, demonstrating a steady progression in workload over the 12 weeks. Table 1 summarizes the changes before during and after training, as well as time spent in HR zones. Body fat decreased from 32.0% to 30.0% over the course of the training, with an estimated loss of 1.6 kg of fat mass, while body mass decreased to 64.8 kg. W_{Peak} increased by 45% from 60 W to 90 W by week 6, while $\text{VO}_{2\text{Peak}}$ increased by 52% from $0.970 \text{ L} \cdot \text{min}^{-1}$ to $1.50 \text{ L} \cdot \text{min}^{-1}$ by week 6. Both failed to increase further by week 12. In contrast, endurance performance during TT_{30} improved throughout the training period from 17.2 W to 26.5 W by week 12. These improvements represent an improvement from baseline of 32.0% at week 4, 46.5% at week 8, and 54.1% at week 12. The individual exhibited a stable mean arterial pressure (MAP) throughout the training period; mean pre-warm-up MAP was 88.1 mmHg, while mean MAP following cool-down was 83.3 mmHg.

Discussion

The purpose of this case study was to evaluate the efficacy of a periodized HIT program in a man without functional use of his lower extremities. Our participant completed 36 training sessions, increasing both maximal and submaximal exercise performance substantially over the course of 14 total weeks. To our knowledge, this is the first case of a person with SCI utilizing HIT to improve $\text{VO}_{2\text{Peak}}$ more than 50% in just 6 weeks, while endurance performance, as measured by TT_{30} , improved by more than 50% by the end of the training program. He also was able to lose 1.6 kg of fat mass, improving his body composition by over 6%. Finally, the participant demonstrated a higher than expected physiological response to exercise, supporting the view that those with SCI require individually designed training programs to account for such responses.

Figure 1 Graphic summary of 14 week arm crank HIT program for a C8/T1 man with spinal cord injury. 36 sessions were completed including four 30 min time trials at weeks 0, 4, 8, and 12, and three $VO_{2\text{ Peak}}$ tests prior to training, at 6 and 13 weeks. For simplicity, the average (Avg) power for individual sessions is shown as gray bars, while a 5 day rolling Avg for power (—) and HR TRIMP (---) depicts overall training trends, indicating that initial cardiovascular adaptation took about 2 weeks and mirrored improvements in power.

There is a dose response relationship from exercise; however exercise intensity is often seen as a critical component in optimizing exercise outcomes in a variety of populations,^{1,6} and is likely the most important factor for improving maximal aerobic power.^{1-4,6} Unfortunately, research on training efficacy for individuals with SCI has lagged well behind able-bodied research. Two common reasons are difficulty recruiting

subjects and the diversity in physiological responses makes it difficult to develop and implement training protocols. Prior research by Jacobs⁷ has shown that resistance training alone improves strength, anaerobic and aerobic power, while Nash *et al.*⁵ were able to promote significant improvements in overall fitness and blood lipids utilizing circuit resistance training. However, little data are available on HIT for individuals

Table 1 Training responses to 12 weeks of high-intensity interval training in a 42-year-old male paraplegic. Total % of training time spent in each Zone is also noted

	Pre-Training	Mid-Training 1	Mid-training 2	Post-Training
<i>Body Composition</i>				
Body Fat %	32.0	—	—	30.0
Fat Mass (kg)	20.3	—	—	18.6
Fat-free mass (kg)	46.1	—	—	46.3
<i>Physiologic Testing</i>				
$VO_{2\text{ Peak}}$ ($\text{mL} \cdot \text{min}^{-1}$)	970	-	1493	1473
W_{Peak}	65	-	93	94
TT_{30} Power (W)	17.2	22.7	25.2	26.5
TT_{30} BLC (mM)	4.3	3.6	3.8	6.7
<i>HR Training Zones</i>				
Zone 1: < 128 bpm	53.1%			
Zone 2: 128–152 bpm	43.0%			
Zone 3: $\geq$ 153 bpm	3.9%			

W_{Peak} = power at $VO_{2\text{ Peak}}$; TT_{30} = 30-minute timed trial; BLC = blood lactate concentration.

with SCI, and they demonstrate that improvements of only 10–20% for lower intensity training programs (e.g. 50%–80% $\text{VO}_{2\text{ Max}}$). Our participant exhibited a substantial improvement in fitness and performance markers within 4 weeks of training, with overall improvement in all testing of about 50%. While peak measures (e.g. $\text{VO}_{2\text{ Peak}}$, W_{Peak}) appeared to plateau by week 6, the participant showed continued improvement in time trial performance up until the end of the program signifying an improvement in endurance. These data support contemporary knowledge on training and performance.^{4,8} indicating that submaximal endurance performance continues to improve in the absence of increases in maximal aerobic power.

It must be noted, however, the participant in this study may represent a unique case. While he had never engaged in any sport or serious training program, he was a very active and highly motivated individual. Despite being diagnosed as a high level paraplegic by two different physicians, his HR and overall functional abilities belied those of a motor complete C8/T1 individual. It is possible that this unique characteristic might account for some of his improvement. Nonetheless, we believe HIT can and should be utilized in the exercise programming of those with SCI.

Practical applications

This case study demonstrates that arm crank HIT can be effectively applied to paralyzed individuals, and may produce relative improvements in maximal aerobic power on par with some classic research by Hickson *et al.*⁴ For example, Hickson *et al.* reported that $\text{VO}_{2\text{ Max}}$ increased an average of 23% over 9 weeks, and more than 50% in some individuals. They also reported that many individuals plateaued in aerobic capacity prior to end of their training period. It appears that like able-bodied individuals, HIT may be more effective than moderate intensity exercise in improving maximal aerobic capacity and body composition. Prior research⁹ supports this notion, as 16 weeks of moderate intensity ACE exercise elicited about a 25% improvement in $\text{VO}_{2\text{ Peak}}$, with minimal improvements in body composition. More importantly, most of the subjects in the latter study either plateaued in training output or exhibited signs of overtraining, whereas this subject showed a clear progression over 14 weeks, further emphasizing the need for properly periodized training programs. This study also underscores the importance of individualized programs for individuals with spinal cord injury, rather than the broad generic training provided by many guidelines. We also believe that the reduced volume of HIT can help minimize overuse injuries of the shoulder.

Conclusions

In summary, we found that a middle-aged man with chronic SCI displayed a marked improvement in cardiovascular fitness and endurance performance following a three-day per week HIT program. The volunteer for this case improved both maximal aerobic capacity and submaximal time trial power output. However, maximal performance plateaued within 6 weeks, supporting the long-held notion that peripheral improvements yield long-term training outcomes.

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Disclaimer statements

Conflict of interest We report no known conflicts of interest.

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