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Please cite this article: **PHYSIOLOGICAL ADAPTATION FOLLOWING FOUR-WEEKS OF HIGH-INTENSITY FUNCTIONAL TRAINING**

Authors: Brian Kliszczewicz², Michael McKenzie¹, Brett Nickerson³; *Vojnosanitetski pregled* (2017); Online First August, 2017.

**UDC:**

**DOI:** https://doi.org/10.2298/VSP170228095K

When the final article is assigned to volumes/issues of the Journal, the Article in Press version will be removed and the final version appear in the associated published volumes/issues of the Journal. The date the article was made available online first will be carried over.
TITLE: PHYSIOLOGICAL ADAPTATION FOLLOWING FOUR-WEEKS OF HIGH-INTENSITY FUNCTIONAL TRAINING

HEADER TITLE: Adaptation to Four-weeks of HIFT

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Conflicts of Interests: There are no conflicts of interest to declare
ABSTRACT

BACKGROUND: High-Intensity Functional Training (HIFT) is a popular mixed-modal program that utilizes both resistance and aerobic based exercises. The aim of this study was to examine the physiological effects of HIFT programing on physically active men (10) and women (10) over a four-week period through the measure of aerobic capacity, anaerobic capacity, and maximal weight lifted. METHODS: Participants first completed a maximal oxygen consumption (VO₂max) test. After 48-hours of rest subjects completed an anaerobic capacity test via the Wingate protocol. Following, the Wingate test subjects performed a 1-repetition maximal test for squat, snatch, and clean at the offsite training location. After pre-measurements were obtained, subjects entered a four-week HIFT intervention and returned to the lab for all post-measurements. RESULTS: Significant improvements were observed in male and female VO₂ max (Pre: 46.7 ± 2.6, 33.7 ± 1.7; Post: 49.0 ± 3.0, 35.0 ± 1.8 ml/kg/min), Peak Wingate Power (Pre: 1206 ± 106, 708 ± 44; Post: 1283 ± 88, 809 ± 38 W) Mean Wingate Power (Pre: 680 ± 46, 704 ± 48; Post: 434 ± 15, 458 ± 18 W)(p <0.05), back squat (Pre: 128.8 ± 8.8, 44.1 ± 6.8; Post: 142.7 ± 9.8, 54.3 ± 6.2 kg) clean (Pre: 82.5 ± 6.2, 24.1 ± 3.4; Post: 92.7 ± 5.8, 33.2 ± 3.3 kg) and snatch (Pre: 59.3 ± 4.4, 20.9 ± 1.7; Post: 69.1 ± 5.3, 25.0 ± 2.3 kg)(p <0.05) respectively. No gender by time interaction was observed (p > 0.05). CONCLUSIONS: HIFT demonstrated rapid physiological improvements in strength, aerobic, and anaerobic capacity following a 4-week intervention in physically active participants.

KEY WORDS: High-Intensity, Strength, Aerobic Capacity, Anaerobic Capacity

INTRODUCTION

In recent years there has been a growing interest towards non-traditional exercise programs that involve high-intensity bouts and require a lower time commitment. Additionally, these programs do not focus on specific aspects of fitness, but rather a broad focus towards general preparedness. The aforementioned programs are commonly referred to as High-Intensity Functional Training (HIFT). These include programs like Insanity, P90x®, and CrossFit®. The unique approach to HIFT programming is the various uses of exercise modalities, ranging from Olympic weight lifting, to bodyweight calisthenics/gymnastic movements, with an emphasis on improving the capacity to perform
large amounts of work in short periods of time. However, despite recent trends in popularity toward HIFT like training (1), little evidence exists in regards to the efficacy of this application on markers of fitness and performance in currently active individuals.

Various acute adaptations occur during the onset of a new exercise program when applied to untrained individuals. Alterations in strength can occur as early as two weeks (2), while alterations in aerobic capacity (i.e. VO$_{2\text{max}}$) can occur as rapidly as six days (3). This is commonly reported to be due to alterations in the neuromuscular system, as well as oxygen related alterations in the cell (2,4). However, when beginning a new exercise program in individuals who are already physically active, alterations and adaptations occur less rapidly. Due to the reduction in adaptation following chronic training, research continually examines the efficacy of exercise programs over longer durations (i.e. 8, 12, 16-weeks). Several studies examining this time period have shown that both aerobic and strength based interventions result in positive alterations in body composition (5,6); while, improvements in performance markers such as muscular strength, anaerobic, and aerobic capacity also occur in variously trained populations (7–9).

Limited information is available on the acute adaptations to a new exercise program for individuals who are already physically active. Furthermore, advocates of HIFT programs purport gains and early physiological adaptations for those who participate (9,10). However, the acute adaptations to HIFT training have yet to be reported for individuals who are already physically active. The acute responses to HIFT training in physically active population would be beneficial for those prescribing this style in order to better assess and track improvements in clients and participants. Therefore, the purpose of this study was to determine the changes in aerobic capacity, anaerobic capacity, and one-repetition maximum in back squat, clean, and snatch following a four-week HIFT program on physically active men and women.
MATERIALS AND METHODS

PROCEDURES:

All participants reported to the Exercise Physiology Laboratory for pre and post intervention testing, which consisted of two laboratory visits 48-hours apart. During the first visit, each subject signed the informed consent and completed a health history questionnaire. Participants then completed a maximal oxygen consumption (VO$_{2\text{max}}$) exercise test on a treadmill using a graded exercise protocol. 48-hours later participants returned to the lab for anaerobic capacity measures via a 30-second Wingate protocol. Following this measure, participants made an appointment at a local CrossFit® affiliate and began their four-week intervention. During the first week of the acclimation period participants were taught proper exercise technique, and then performed a 1-repetition maximal (RM) test for squat, snatch, and clean at the CrossFit® affiliate prior to the start of the 4-week intervention. Following the four-week intervention, participants returned to the laboratory for aerobic and anaerobic capacity testing and to the affiliate for 1RM testing.

HIFT INTERVENTION

The HIFT intervention chosen for this study was CrossFit®. Following the first two lab visits (i.e., after aerobic and anaerobic capacity testing), participants made an appointment at a local CrossFit® box affiliate where they would be instructed by a certified Instructor and exercise science graduate. The participants all began an introductory week to learn the basics of HIFT. Participants were provided with a full group class schedule for the next four-weeks. Participants were informed they could attend as many classes per week with no restrictions, however a minimum of three days per week was required in order to remain in the study. Participants trained with the normal HIFT classes performing the workouts as prescribed by the head trainer of the affiliate. A typical class would start with a warm-up, a strength/power component, then a HIFT bout ranging from 7-25 minutes in duration. Participants were instructed and encouraged to modify each workout as needed. Following the 4-weeks of training, each subject performed the 1RM tests again under the same supervision, as well as the VO2 max, and Wingate testing, with each bout separated by at least 48 hours.
**Participants:**

Twenty participants (10 male, 10 female) were recruited for the current study. Participant characteristics are shown in table 1. All participants were classified as recreationally trained by self-identifying as currently participating in at least 30-bouts of planned physical activity for at least 30-minutes three times per week for at least the last 90-days. Additionally, all participants must have participated in both aerobic and weight training activities. None of the participants had previous HIFT experience or reported any colds, sicknesses, or orthopedic conditions that could limit exercise participation. This study was approved the Institutional Review Board of the host university prior to recruitment and data collection.

**Measures:**

**Maximal Exercise Capacity, Strength and Anthropomorphic Measurements.**

Aerobic capacity was determined through a graded exercise test; expired gases were analyzed by a True 1 analyzing system calibrated to known gases. Heart rate (Polar monitors) was obtained during the test. Each participant performed a 3-5 minute warm-up at a self-selected speed. Participants then breathed through a one-way valve, which enabled expired gases to be processed by the True 1 analyzing system. Participants started the test at a self-selected running speed at 0% grade. The grade was increased 2% every 2-minutes until VO₂ leveled off or the subject stopped the test (8 -10 minutes) (11). All participants attained their age predicted maximal heart rate (HR) ± 10 bpm, reported an RPE > 19 on the Borg scale during the last stage of the test and had RER > 1.10.

Anaerobic capacity was obtained approximately 48-hours following the first visit. For testing, participants returned to the laboratory to have their peak and mean power measured using a Wingate test. Briefly, using a Lode cycle ergometer, subjects pedaled at a self-selected moderate intensity for 5-minutes as a warm-up. Then participants performed the Wingate test against a resistance equal to 7.5% of their bodyweight on an electronically controlled braking bike and had both their mean and peak power measured.
Muscular strength assessment occurred after a 1-week introduction to proper form and techniques in HIFT. After the one-week introduction, subjects performed a 1-RM in the following order on the same day: snatch, clean, and back squat. The progression was self-selected and participants were allowed unlimited attempts at every weight and achieved their 1RM within 4 attempts, with no time limit provided. Each of the attempts were supervised by the certified HIFT instructor, as well as the PI, who is a certified strength and conditioning specialist (CSCS).

Statistical Analysis

All data were analyzed with SPSS version 24 (IBM, New York, NY). Prior to data analysis, variables underwent a Shapiro-Wilk test in order to determine normality of the data distribution. The effect of the intervention was determined using a repeated measure 2 x 2 ANOVA (time by gender) and statistical significance was set at priori at p < 0.05. If there was an interaction effect, a Scheffe’ post-hoc test was utilized to identify differences.

Table 1. Subject Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Age (years)</td>
<td>26.6 ± 1.9</td>
<td>28 ± 2.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178 ± 2.3</td>
<td>167.5 ± 1.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>90.5 ± 5.8</td>
<td>72.2 ± 4.8</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>17.7 ± 2.0</td>
<td>23.7 ± 2.1</td>
</tr>
</tbody>
</table>

(Mean ± Standard Deviation)
RESULTS

All 20 participants completed the study. Compliance was 100%, as all subjects attended four-weeks of classes a minimum of three times a week. There were no injuries reported to the investigators, or to the trainers. The Shapiro-Wilk test demonstrated that sprint data was normally distributed for all conditions. Following four-weeks of training all measured variables showed significant main effects in both genders. Table 2 shows laboratory measures made. Participant VO\textsubscript{2} max demonstrated a main time effect (p = 0.016), and no time x gender effect (p = 0.415). Peak Wingate Power demonstrated a main time effect (p = 0.010), and no time x gender effect (p = 0.712). Mean Wingate Power demonstrated a main time effect (p = 0.026), and no time x gender effect (p > 0.999). Table 3 shows 1 RM measures made. Participant back squat demonstrated a main time effect (p < 0.001), and no time x gender effect (p = 0.327). Participant clean demonstrated a main time effect (p < 0.001), and no time x gender effect (p = 0.648). Participant snatch demonstrated a main time effect (p < 0.001), and a main time x gender effect (p = 0.042).

DISCUSSION

The purpose of this study was to determine the changes in aerobic capacity, anaerobic capacity, and one-repetition maximum in back squat, clean, and snatch following a four-week HIFT program on physically active men and women. The primary findings demonstrated time-dependent improvements in aerobic capacity, anaerobic capacity, squat, clean, and snatch. A gender-by-time effect was only observed in pre and post snatch measures. Further points of consideration are provided below.
### Table 2. Laboratory Performance: Aerobic & Anaerobic

<table>
<thead>
<tr>
<th>Test</th>
<th>Male</th>
<th>Confidence Interval</th>
<th>P Value</th>
<th>Effect Size</th>
<th>Female</th>
<th>Confidence Interval</th>
<th>P Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO₂ Max Pre</strong> (ml/kg/min)</td>
<td>46.7 ±2.6</td>
<td>± 1.61</td>
<td></td>
<td></td>
<td>33.7 ± 1.7</td>
<td>± 1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VO₂ Max Post</strong> (ml/kg/min)</td>
<td>49.0 ± 3.0*</td>
<td>± 1.86</td>
<td>0.032</td>
<td>-0.2419</td>
<td>35.0 ± 1.8</td>
<td>± 1.12</td>
<td>0.239</td>
<td>0.3480</td>
</tr>
<tr>
<td>Wingate Peak Power Pre (W)</td>
<td>1206 ± 106</td>
<td>± 65.7</td>
<td></td>
<td></td>
<td>708 ± 44</td>
<td>± 27.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wingate Peak Power Post (W)</td>
<td>1283 ± 88*</td>
<td>± 54.54</td>
<td>0.015</td>
<td>-0.3675</td>
<td>809 ± 38</td>
<td>± 23.55</td>
<td>0.025</td>
<td>-0.7755</td>
</tr>
<tr>
<td>Wingate Mean Power Pre (W)</td>
<td>680 ± 46</td>
<td>± 28.51</td>
<td></td>
<td></td>
<td>434 ±15</td>
<td>± 29.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wingate Mean Power Post (W)</td>
<td>704 ± 48*</td>
<td>± 9.3</td>
<td>0.018</td>
<td>+0.9634</td>
<td>458 ± 18*</td>
<td>± 11.16</td>
<td>0.047</td>
<td>+0.9592</td>
</tr>
</tbody>
</table>

A * denotes a significant time main effect. A # denotes a main effect for time x gender.
(Mean ± Standard Deviation)

**Markers of Strength**

The markers of muscular strength examined in this study were the Squat, Clean, and Snatch. Following the HIFT intervention, significant strength adaptations in each marker occurred, suggesting that the four-week time period was sufficient enough to elicit changes
in physically active participants. Acute strength adaptations are common among sedentary individuals beginning a new exercise program due to neural adaptations (e.g., synchronization and recruitment of additional motor units, increased neural drive, etc.). However, these adaptations are less observed in those who are already physically active. For instance, Ahtiainen et al. examined the difference in strength adaptation between trained and untrained participants, where significant alterations were observed only at 14-weeks(7), 10-weeks later than the observation made in the current study. It is important to note that even though the participants in the current study were physically active, their experience and technique associated with the examined markers (i.e. power clean and snatch) were limited and therefore a likely mechanism for the observed improvements following the 4-week intervention.

Neuromuscular adaptation is commonly attributed to early improvements in strength (2) and is greatly related to the learning and coordination of the muscle groups as it relates to the specificity of training (12). This notion is supported by a 60-day unilateral strength training study performed by Narici et al., which yielded an approximate 9% improvement in maximal voluntary contraction with no improvements in cross-sectional area; however, an approximate 25% improvement in neuromuscular activity (via integrated electromyographic activity) occurred (13). An alternate explanation for the observed improvements in strength within this study is early skeletal muscle hypertrophy. This is a rare occurrence; however, there are a few documented cases of early adaptive hypertrophy. For example, significant gains in strength and hypertrophy were observed in recreationally trained participants by the third week of a 35-day high-intensity resistance training study (14). It is important to note that the examination of the hypertrophic response to training is outside the scope of this study, but the notion presents an alternative explanation for significant gains in strength observed during the 4-week training period.
Table 3. Laboratory Performance: Strength

<table>
<thead>
<tr>
<th>Test</th>
<th>Male</th>
<th>Confidence Interval</th>
<th>P Value</th>
<th>Effect Size</th>
<th>Female</th>
<th>Confidence Interval</th>
<th>P Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Squat Pre (kg)</td>
<td>128.8 ± 8.8</td>
<td>±5.45</td>
<td></td>
<td></td>
<td>44.1 ± 6.8</td>
<td>±4.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Squat Post (kg)</td>
<td>142.7 ±9.8*</td>
<td>±6.07</td>
<td>0.0006</td>
<td>-0.5980</td>
<td>54.3 ± 6.2*</td>
<td>±3.84</td>
<td>0.008</td>
<td>-0.6168</td>
</tr>
<tr>
<td>Clean Pre (kg)</td>
<td>82.5 ± 6.2</td>
<td>±3.84</td>
<td></td>
<td></td>
<td>24.1 ± 3.4</td>
<td>±2.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean Post (kg)</td>
<td>92.7 ± 5.8*</td>
<td>±3.59</td>
<td>0.0002</td>
<td>-0.6474</td>
<td>33.2 ± 3.3*</td>
<td>±2.05</td>
<td>0.0007</td>
<td>-0.8052</td>
</tr>
<tr>
<td>Snatch Pre (kg)</td>
<td>59.3 ± 4.4</td>
<td>±2.73</td>
<td></td>
<td></td>
<td>20.9 ± 1.7</td>
<td>±1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snatch Post (kg)</td>
<td>69.1 ± 5.3*#</td>
<td>±3.28</td>
<td>0.002</td>
<td>-0.7092</td>
<td>25.0 ± 2.3*#</td>
<td>±1.43</td>
<td>0.004</td>
<td>-0.7118</td>
</tr>
</tbody>
</table>

A * denotes a significant time main effect. A # denotes a main effect for time x gender.
(Mean ± Standard Deviation)

Aerobic performance

HIFT style programming is not traditionally prescribed for improvements in aerobic performance. However, recent research has shown increases in oxygen consumption following high-intensity training (15), and therefore garnered more interest in the scientific community. For instance, Helgerud et al., examined the effects of four different types of exercise modalities over an eight-week period in aerobically trained males; two of the programs were aerobic type, continuous, and of long duration (i.e. 25-45 min between 70 and 85% HR\text{max}), while the other two were high-intensity intervals (i.e. 47 repetitions of 15-sec activity at 90-95% HR\text{max}, and 15 sec recovery at 70%, vs. four 4-minute 90-94% and 3-minute recovery at 70% HR\text{max}) (16). Upon the completion of the eight-weeks, only
those who participated in the high-intensity groups reported significant increases in \( \text{VO}_{2\text{max}} \): (pre: 60.5 ± 5.4 vs. post: 64.4 ± 4.4 ml/kg/min\(^{-1}\))/(pre: 55.5 ± 7.4 vs. post: 60.4 ± 7.3 ml/kg/min\(^{-1}\))(respectfully) (16). Additionally, six-weeks of high-intensity cycling interval training was enough to elicit a 7 ml/kg/min\(^{-1}\), which was comparable to the 5 ml/kg/min\(^{-1}\) observed following an aerobic training protocol (9). The findings of improved \( \text{VO}_{2\text{max}} \) following the HIFT intervention in the current study support the literature in that high-intensity based training is an effective mode for improved \( \text{VO}_{2}\).

Another important consideration is the time frame of the current study. Though it is well established that aerobic capacity improves following multiple weeks of training (i.e., ≥ eight-weeks) (7,16,17), little empirical evidence exists regarding training protocols less than eight-weeks in physically active participants. In a study by Burgomaster et al. researchers observed an almost two-time improvement in muscle endurance after two-weeks of high-intensity sprint training in physically active participants (18). Despite this, no improvements in oxygen consumption was observed following the two-week intervention (18). Similarly, a seven-day HIT overload training study was performed on competitive cyclist and found significant improvements in time trial performance, despite no observed change in physiological factors (19). Conversely, a two-week sprint cycling training protocol improved peak oxygen consumption by 7% within sedentary and overweight participants (20). The two-week sprint cycling study, in conjunction with the current findings, supports the notion that rapid improvement in aerobic adaptation can occur following HIFT. Currently, there are a limited number of studies that provide insight into the mechanisms responsible for early aerobic adaptation following HIFT like programming. Due to conflicting results within the current literature further research in this area is required.

Though it is outside the scope of the current study, several physiological factors may have played a role in the rapid improvement in aerobic performance. A commonly observed adaptation following High Intensity Training (HIT) training is an increase in peripheral vascular structure and function. This results in the improved delivery of \( \text{O}_2 \) to the tissues and subsequent improved \( \text{a-vO}_2 \) difference (21). However, it is unlikely that vascular structure increased during the 4-weeks of HIFT; rather, it is more probable that an improvement of vascular function and control contributed to the observed improvement in \( \text{VO}_{2\text{max}} \). An important distinction to make between HIT and HIFT is the modality of exercise being utilized. Most aerobic and HIT training protocols utilize single modality
such as running or cycling (9,20,22), while HIFT training incorporates aerobic, anaerobic and resistance based exercise all in one workout. Many of the exercise movements in HIFT include upper body movements (e.g. push-press, push-up, pull-up, etc.). The reason this is important to note is the presence of the pressor reflex, which has been shown to more rapidly elevate HR and place more stress on hemodynamics (8), thus presenting a potential mechanism for adaptation.

*Anaerobic markers*

Participants of the study each performed a Wingate Test before and after the 4-week HIFT intervention. Significant increases in post-peak and post-mean power output were observed in both males and females. These results support the hypothesis that improvements in anaerobic performance would occur following the short 4-week intervention. It is well established that the participation in HIT like programming results in anaerobic improvements (i.e., peak power and mean power) (15,23). For instance, untrained individuals have shown improvements in anaerobic performance (5 - 28%) following HIT training ranging from 2-14 weeks (23). Conversely, a two-week sprint interval training program in physically active participants improves anaerobic performance, which was suggested to be due to improved cellular buffering systems (22). This supports the findings of the current study, which observed an increase of mean power output 3.5% (male) and 5.5% (female) and peak power output 6.4% (male) and 14.1% (female).

Though the participants of this study were physically active, they did not regularly engaging in high-intensity exercise, and thus more liable to respond to HIFT training through the principle of anaerobic overload. Therefore it is possible that these “physically active subjects” behaved similar to an untrained person in regard to anaerobic training. The general postulation in regards to adaptation is related to improvements in muscle buffering capacity (23), improved muscle quality (21) and glycogen stores (21,22).
Study Limitations

Though this study was a novel attempt to examine the influences of a 4-week HIFT intervention of physiological markers of fitness in physically active individuals, it was not without its limitations. The sample size was a limiting factor of this study, though the overall effects were great enough to observe significant changes, a larger data set would provide greater insight into the influences of this intervention. Furthermore, future studies should include multiple time points that span a greater period of time. The current study provides a needed understanding of the early influences of a HIFT intervention; however, a greater timeline would allow for a better understanding of the rate and degree of physiological adaptation. Lastly, biomarkers of health such as lipid profile and glucose regulation should be examined pre and post HIFT intervention to provide a more holistic approach to examining adaptation.

In conclusion, HIFT demonstrated rapid physiological improvements in muscular strength, aerobic capacity, and anaerobic capacity following a 4-week intervention in physically active participants. Given the starting training status of the participants and the relatively short duration of the intervention, these findings demonstrate HIFT to be a unique and an effective method of training to induce overall markers of fitness.

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Received on February 28, 2017.
Revised on May 25, 2017.
Accepted on May 29, 2017.
Online First August, 2017.