A 6-week Sprint Interval Training Program Changes Anaerobic Power, Quadriceps Moment, and Subcutaneous Tissue Thickness

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Abstract
We examined the effects of a 6-week 40-m one-way sprint interval training program (based on sprint time). 13 untrained healthy male collegiate students performed six 40-m sprints with a 60-s resting interval between sprints during the first week, and one sprint was added each week until the sixth week. If the 40-m sprint time exceeded 110% of the fastest baseline 40-m sprint time, the run was repeated. Repeated-sprint cycling test (every 3 weeks), quadriceps moment (every 2 weeks), and abdominal and thigh subcutaneous tissue thickness (every 2 weeks) were measured. Compared to baseline, mean power output improved at week 3 (16.27 vs. 17.73 Watt/kg, p = 0.004). Regardless of side, quadriceps moment began to increase at week 4 (2.88 vs. 3.15 N·m/kg, p = 0.03). Subcutaneous tissue thickness was reduced at week 2 (abdominal: 11.19 vs. 9.65mm, p = 0.01; thigh: 9.17 vs. 8.12mm, p = 0.009). Our results suggest that (1) sprint training with an intensity of 110% of the fastest baseline 40-m sprint time with the addition of one sprint per week produces similar effects to other training programs, and (2) untrained individuals need 4 weeks of training for strength development in the quadriceps and 2 weeks for reduction in fat tissue thickness.

Introduction
In the athletic environment, individuals practice physical training programs to improve or maintain muscular strength, power, and endurance. Among strength and conditioning exercises, sprint interval training is commonly performed for aerobic [2, 18] and anaerobic power [1, 14, 21]. This type of training consists of repetitive alternation between a shorter period of vigorous exercise (work) and a longer period of low-intensity (recovery) activity. Vigorous and low-intensity exercises are typically defined as resulting in 80 and 30–45% of the maximal heart rate (or higher), respectively [32]. The work to recovery ratio can range from 1:1 to 1:3 for oxidative improvement and from 1:3 to 1:5 for a fast glycolysis energy system [3]. Long-term physiological adaptations to sprint interval training include a reduced concentration of muscle phosphocreatine in 6 weeks [5], an increased concentration of muscle glycogen in 6 weeks [5, 30], and an increased lactate or ventilation threshold in 2 weeks [19], 4 weeks [34], or 6 weeks [6]. Cardiovascular responses include an increased stroke volume in 8 weeks [8], an increased cardiac output in 6 weeks [24], and a reduced decrease in heart rate immediately after exercise in 6 weeks [25]. A combination of the aforementioned exercise adaptations occurs as a result of fatigue delay. For instance, a 4-week interval training program increases the time to exhaustion during maximal cycling or treadmill exercises [20, 34]. The intensity of sprint interval training is often determined by the percent maximal oxygen consumption (VO₂max) [6, 12]. Despite its popularity [7, 34] and the support of scientific evidence [13], this method has limited practicality. First, this method requires laboratory equipment and trained personnel. Therefore, coaches and trainers must be familiar with the operation of these devices and application of the test protocols. Second, exercise performed on equipment such as a cycle ergometer or treadmill is not functional [27] because athletes play on the ground (e.g., basketball court or soccer pitch). Therefore, a simple and convenient method of intensity determination needs to be developed.
ing training intensity based on an individual’s sprint time could be a convenient alternative method.

The next logical step in the validation of a relatively novel method of determining training intensity would be to compare its training effects with those of existing methods. Training effects that can be examined include aerobic power [7,33], anaerobic power [14,23], muscle strength [2], heart rate [25], cardiac output [5,8,24], and body composition [38,39]. We were particularly interested in the training adaptations in anaerobic power, quadriceps moment, and subcutaneous tissue thickness of the quadriceps. We did not include measurements of aerobic power or cardiovascular function due to the energy system used in our 40-m sprint interval training. Hence, the goal of this study was to observe the effects of a 6-week 40-m sprint interval training program (the intensity of which was determined by the sprinting time) on anaerobic power, quadriceps moment, and subcutaneous tissue thickness in healthy untrained young people. Coaches and training personnel would benefit from this study, as it illustrates a simple field method of determining the training intensity and minimum duration required to improve each parameter.

Methods

Study design
To examine training effects, we measured anaerobic power, quadriceps moment, and subcutaneous tissue thickness. The 40-m sprint time and maximal heart rate were also recorded so that the training intensity could be compared throughout the training period. The independent variable was time (baseline to week 6). Anaerobic power was assessed every 3 weeks, whereas quadriceps moment, subcutaneous tissue thickness, body mass, and percent body fat were assessed every 2 weeks. The 40-m sprint time (average and max) and maximal heart rate were recorded every week. The selection of the above time points was based on previous studies indicating that anaerobic power and quadriceps moment changed in 3- [37] and 2-week [18,19] training periods, respectively.

Subjects
Before conducting this study, we obtained approval from the university’s Institutional Review Board. This study was conducted according to the Declaration of Helsinki and meets the ethical standards of the journal [16].

Our sample size was determined based on an expected change in power output (Watt/kg) of 1.6 and a standard deviation (SD) of 1.7 (effect size of 0.94) with an alpha of 0.05 and a beta of 0.2 [22]. This calculation allowed us to estimate the need for 11 subjects. Initially, 15 healthy, recreationally active male collegiate students with no lower extremity injury in the past 6 months, no history of lumbar spine or lower extremity conditions resulting in surgery, and no experience in any type of interval training provided written informed consent and participated. After initiation of sprint interval training, 2 subjects were dismissed: one had an injury (a hamstring strain) and another did not want to participate; thus, 13 subjects (age, 22.5±2.3 years; height, 175.0±4.9 cm; mass, 71.3±8.6 kg) were finally analyzed. During the training period (6 weeks), subjects were asked to maintain their habitual diets and not to consume medications or supplements. They were also asked not to participate in any physical activity other than the activities of daily living.

Testing procedures
All subjects underwent baseline measurements prior to participation in the 40-m sprint interval training. Baseline measurements were recorded on 3 separate days (day 1: anaerobic power, day 2: quadriceps moment, and day 3: 40-m sprint, heart rate, and subcutaneous tissue thickness).

Anaerobic power was assessed through measurement of the mean power output during a 3-s repeated-sprint cycling test [26] performed on a standardized stationary cycle ergometer with fitted toe clips and rounded handlebars (232C model 50, Combi, Tokyo, Japan). Prior to the test, subjects adjusted the seat height of the cycle ergometer. Once seated on the cycle ergometer, each subject performed a 5-min warm-up to prevent injury. The seat height was marked for subsequent visits. Subjects performed 2 repetitions of an alternating testing protocol (a 3-s sprint and a 3-min rest period between sprints [15]). From a static start, subjects were asked to pedal as many revolutions as possible during cycling sprints. Cycling resistive load was set at 0.03 kg/kg of body mass [26]. An on-line built-in computer in the cycle ergometer sampled the number of pedal revolutions (rpm) every 0.01 s (100 Hz). The mean values during sprinting (a total of 6-s) were calculated and normalized to body mass for analysis. For quadriceps moment, subjects performed a maximal voluntary isometric contraction (MVIC) on a dynamometer with the knee and hip locked at 90° and 110° flexion, respectively (Cybex 770, Lumex Co., Ronkonkoma, NY, USA; sampling rate: 100 Hz). The chest, pelvis, and thigh were secured with straps, and subjects crossed their arms over their chests to minimize the contribution of other muscles during MVIC. Prior to measurements, subjects performed a warm-up consisting of 3 isometric contractions at 30, 50, and 75% of maximal effort. The results of 3 MVIC (5-s) trials on each side were recorded, with a 60-s rest period between contractions. MVIC values between 2 to 4s were chosen to represent the MVIC in each trial [31] and were normalized to body mass (N-m/kg). Verbal encouragement (“kick, kick, harder”) and visual feedback were provided via a computer monitor during measurements.

A skinfold pinch caliper (Lange Skinfold Caliper, Cambridge Scientific Industries Inc., Cambridge, MA, USA) was used to assess subcutaneous tissue thickness. Subjects lay supine on a treatment table, and subcutaneous tissue thickness was sampled at the abdomen (2 cm from the dominant side of the umbilicus) and thigh (midpoint between the proximal border of the patella and the inguinal crease on the subject’s dominant side) [28]. Measurement sites were marked first, and assessments were taken in the order of abdomen and thigh. The results of 3 trials were obtained, averaged, then divided by 2 [17] for quantification of subcutaneous tissue thickness.

For the 40-m sprint, subjects were instructed to sprint (from a standing start position) through 2 pairs of infrared timing sensors (Brewer Timing Systems, Draper, UT, USA) located 40-m apart, in an indoor handball court. 3 sprints were performed (with a 60-s rest interval between sprints), and each subject’s average sprint time was determined. During the sprints, the subject’s maximal heart rate was also recorded using a monitor (Polar RS400, Polar Electro, Kempele, Finland). Subjects wore the monitor on their chest and an affiliated watch on their wrist. Maximal heart rate was recorded immediately after the completion of each sprint (no less than 10s after).

After baseline measurements, subjects began the 40-m sprint interval training. The same methods used in the baseline tests were applied, except that subjects re-ran if the 40-m sprint time...
exceeded 110% of the fastest time measured during baseline tests. Based on the results of our pilot tests, this training intensity is equivalent to 85% of the age-predicted maximal heart rate (208 – 0.7 × age in healthy adults [36]). For example, if a subject’s fastest sprint time was 5.66 s, 6.23 s was used as the cut-off time for each sprint each week. This means that the cut-off sprint time was not determined each week. We employed this method because (1) examining training effects of the same intensity for 6 weeks was the purpose of current study, and (2) determining cut-off time each week may have affected subjects’ submaximal effort during sprinting. A 60-s rest period (walking back to the starting line) was given between sprints. The maximal heart rate was also recorded during the training period using the same method as for baseline measurement. Subjects performed 3 training sessions per week, beginning with 6 sprints in the first week, and one sprint was added each week; thus, 11 sprints were completed in the sixth week. During the first week, subjects were trained for 12 min, along with a 15-min warm-up and cool-down. Each run and recovery period took approximately 2 min; hence, 2 min were added each week. The total training time for the 6-week training was 258 min. Although the 40-m sprint training was performed 3 times per week, on the days anaerobic power and quadriceps moment were measured, subjects did not perform sprint training. Therefore, a total of 14 bouts of sprint training were performed during the 6-week training period. The 40-m distance was selected because our interval training aimed at an adaptation of the anaerobic energy system and sprints are usually no longer than 40-m in sports activities (e.g., soccer) [11].

Statistical analyses
Mean and standard deviation (SD) values were calculated from 3 trials of each measurement for each time point. To test time effect, we performed one-way mixed-model analysis of variances (anaerobic power, subcutaneous tissue thickness, 40-m sprint time, maximal heart rate, and body mass) and two-way mixed model analysis of variance (quadriceps moment). We also performed Tukey-Kramer pairwise comparisons as post-hoc tests. (SAS 9.3, SAS Institute Inc., Cary, NC, USA, p < 0.05 for all tests).

We calculated effect sizes (ES = [(X – X)] / σ_p) and their 95% confidence intervals (ESCI = ES ± σ_p) when significant between-time differences were detected.

Results

Anaerobic power improved throughout the training period (F_6,24 = 11.07, p = 0.0004, Table 1). Anaerobic power was 8.2% greater at week 3 (p = 0.004, ES = 0.73, ESCI = −0.03 to 1.50) and 9.8% greater at week 6 (p = 0.0005, ES = 0.91, ESCI = 0.17 to 1.66) than at baseline. However, subjects did not show improvement from week 3 to week 6 (p = 0.72).

We did not observe side-specific effects of the training on quadriceps moment over time (interaction: F_3,84 = 0.03, p = 0.99). Regardless of side, however, quadriceps moment increased (time main effect: F_3,84 = 4.37, p = 0.007, Table 2). Compared to baseline, quadriceps moment began to increase at week 4 (9.7%, p = 0.03, ES = 0.49, ESCI = 0.24 to 0.74) and was maintained until week 6 (11.1%, p = 0.007, ES = 0.54, ESCI = 0.27 to 0.80). Quadriceps moment did not improve further between week 4 and week 6 (p = 0.97).

Table 1. Anaerobic power relative to body mass.

<table>
<thead>
<tr>
<th>Unit: Watt/kg</th>
<th>Baseline</th>
<th>Week 3</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean power output</td>
<td>16.27 (1.91)</td>
<td>17.73 (2.07)</td>
<td>18.03 (1.96)</td>
</tr>
</tbody>
</table>

Different from baseline: *p = 0.004 (ES = 0.73, ESCI = −0.03 to 1.50) and †p = 0.0005 (ES = 0.91, ESCI = 0.17 to 1.66); Values are mean (SD)

Table 2. Quadriceps moment relative to body mass.

<table>
<thead>
<tr>
<th>Unit: N m/kg</th>
<th>Baseline</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVIC (right)</td>
<td>2.91 (0.44)</td>
<td>3.18 (0.73)</td>
<td>3.24 (0.72)</td>
<td>3.30 (0.78)</td>
</tr>
<tr>
<td>MVIC (left)</td>
<td>2.84 (0.51)</td>
<td>3.12 (1.02)</td>
<td>3.14 (0.82)</td>
<td>3.19 (0.89)</td>
</tr>
<tr>
<td>MVIC (total)</td>
<td>2.88 (0.48)</td>
<td>3.15 (0.89)</td>
<td>3.19 (0.77)</td>
<td>3.24 (0.84)</td>
</tr>
</tbody>
</table>

Different from baseline: *p = 0.03 (ES = 0.24 to 0.74) and †p = 0.007 (ES = 0.54, ESCI = 0.27 to 0.80); MVIC: maximal voluntary isometric contraction; Values are mean (SD)

Table 3. Subcutaneous tissue thickness.

<table>
<thead>
<tr>
<th>Unit: mm</th>
<th>Baseline</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen</td>
<td>11.19 (2.90)</td>
<td>9.65 (3.05)</td>
<td>9.62 (2.89)</td>
<td>8.79 (2.87)</td>
</tr>
<tr>
<td>Thigh</td>
<td>9.17 (1.84)</td>
<td>8.12 (1.84)</td>
<td>8.00 (1.88)</td>
<td>7.33 (1.32)</td>
</tr>
</tbody>
</table>

Different from baseline: *p = 0.01 (ES = −0.62 to 1.66), †p = 0.01 (ES = 0.54, ESCI = −0.57 to 1.66), and ‡p = 0.0001 (ES = 0.83, ESCI = −0.27 to 1.94) Different from baseline in thigh: *p = 0.09 (ES = 0.57, ESCI = −0.13 to 1.28), †p = 0.003 (ES = 0.63, ESCI = −0.07 to 1.35), and ‡p = 0.0001 (ES = 1.15, ESCI = 0.54 to 1.77); Values are mean (SD)

Our sprint interval training was also effective to reduce subcutaneous tissue thickness in the abdomen (F_3,36 = 8.81, p = 0.0002) and the thigh (F_3,36 = 12.02, p = 0.0001). Compared to baseline, abdomen (13.8%, p = 0.01, ES = 0.52, ESCI = −0.62 to 1.66) and thigh (11.5%, p = 0.009, ES = 0.57, ESCI = −0.13 to 1.28) began to decrease at week 2 (Table 3). After week 2, however, we did not observe further reduction in both sites. Baseline sprint time was faster than that of each week (F_6,72 = 5.88, p = 0.0001, Table 4). Mean sprint times (SD) at baseline, and through week 1 and 6 were 5.66 (0.20) and 5.80 (0.20) s, respectively.

Maximal heart rate (F_6,72 = 0.4, p = 0.88) and body mass (F_3,36 = 0.60, p = 0.62) were not different from baseline through the 6-week training period (Table 5).

Discussion

We were interested in how a 6-week 40-m sprint interval training program – training intensity determined by 110% of fastest sprint time – would change anaerobic power, quadriceps moment, and subcutaneous tissue thickness. Our training protocol showed similar effects to many others [1, 2, 7, 14, 20, 21, 29]. Other studies [1, 2] reported a 10.6% improvement in anaerobic power in 4–7 weeks [7, 14, 20, 21, 29]. Other studies [1, 2] reported a 10.6% improvement in anaerobic power in 4–7 weeks [7, 14, 20, 21, 29].
the maximal cadence against a resistance equivalent to 0.075 kg/kg of body mass for 30 s on the cycle ergometer. Since we observed a 8.2% improvement in anaerobic power in 3 weeks, it can be assumed that our training protocol produced physiological effects (e.g., creatine kinase, phosphofructokinase, pyruvate kinase, and lactate dehydrogenase) similar to those in the previous study [29]. We observed an improvement in the third week of training but no further increase in the sixth week. Since anaerobic power has been shown to increase by up to 25% [21] 7 weeks after the initial training, further improvement in anaerobic power might be achieved if the training period was extended or the running intensity was adjusted.

We observed improvements in quadriceps moment in 4 weeks. Previously, increases in quadriceps moment due to sprint interval training have been shown to occur in 4–8 weeks [2, 15, 37]. Of these studies [2] reported training effects in 3 weeks. In that study, subjects performed 6 sessions of 4 to 6 sets of 30-s cycling sprints with 5-min rest intervals. The intensity of the training was determined with 30-s all out sprints (100% of maximal cadence against a resistance equivalent to 0.075 kg/kg of body mass) on an ergometer. In that study, a 7.6% improvement in quadriceps moment was detected, compared to the 9.7% increase in our study. This indirect comparison suggests that training effects are equivalent between the previous method and ours.

Quadriceps moment did not increase from the fourth week to the sixth week (p=0.97). This may have been due not only to the training volume but also the training intensity. It is well established that neural adaptation (e.g., motor unit recruitment, firing frequency, and synchronization) requires an initial strength improvement in untrained people [10]. Our subjects were not strength- or conditioning-trained. We speculate, therefore, that neural adaptation [10] may have contributed to strength development in the 4-week training period. The lack of further improvement in the measurement from week 4 to week 6 may indicate that our interval training protocol was not sufficient to maximize neural efficiency in quadriceps moment. Increasing the training volume and intensity may be necessary. If neural adaptation has been maximized, in contrast, additional resistance training would be needed for further strength improvement.

Many studies reported that changes in body composition require 2-week to 3-month training periods [24, 35, 38–40]. Among those, 2 studies observed an increase in plasma membrane fatty acid-binding protein (FABPpm) content [35] and resting fat oxidation rate [40] in 2 weeks. In the first study [35], recreationally active people performed 7 sessions of a 60-min cycling exercise at an intensity of 60% V̇O2peak. Another study [40], obese people performed 6 sessions of repeated 30-s cycling sprint at high intensity (0.065 kg/kg of fat free mass). Since training intensity in our study was submaximal and other parameters were similar to previous studies [35, 40], increased efficiency in fat metabolism (e.g., FABPpm) may explain a reduction in subcutaneous tissue thickness of the abdomen and thigh. Additionally, loss of water weight at the initial training (up to 4–5 training sessions) may have possibly contributed to the results of assessment at week 2.

During the baseline measurements, subjects were asked to sprint with maximal effort, whereas they ran with submaximal effort during the training period. The maximal heart rate throughout the 6-week training period did not differ from the baseline value. This may be an important observation because subjects ran with submaximal effort during the training period (110% of the fastest 40-m sprint time achieved during baseline measurements). Since our subjects performed a high-intensity activity in a very short working time (average sprint time: less than 6 s), the anaerobic energy system (e.g., phosphagen) was mostly responsible for sprinting. Additionally, 6 weeks are not sufficient to produce training adaptation [8, 9], and changes in factors related to cardiovascular function (e.g., stroke volume and cardiac output) were unlikely. It can be assumed that the training intensity was maintained throughout the training period, even though subjects ran at submaximal intensity (approximately 85% of the age-predicted maximal heart rate) [38]. This indirectly indicates that subjects were trained with high intensity in terms of heart rate.

Since we only tested the training effects within 6 weeks, it is unclear how long the training effects would last. A previous study [25] reported that anaerobic power returned to the prereading level following 6 weeks of detraining. In future research, detraining effects should be monitored. Our subjects were active young people; thus, if training were performed with other groups such as trained or sedentary people, it would be necessary to use a different intensity to achieve similar results. During the training period, our subjects did not participate in any physical activity other than the activities of daily living (ADL). For future studies, we suggest recruiting a narrow population in terms of ADL to eliminate heterogeneity in physical activity levels. We do not know if a shorter running distance (20 m or 25 m) would produce similar training effects.

Table 4 Average and max (fastest) 40-m sprint time.

<table>
<thead>
<tr>
<th>Unit: s</th>
<th>Baseline</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average sprint time</td>
<td>5.66 (0.20)</td>
<td>5.82 (0.21)</td>
<td>5.83 (0.21)</td>
<td>5.79 (0.22)</td>
<td>5.80 (0.19)</td>
<td>5.76 (0.21)</td>
<td>5.81 (0.17)</td>
</tr>
<tr>
<td>Max sprint time</td>
<td>5.66 (0.20)</td>
<td>5.93 (0.20)</td>
<td>5.57 (2.20)</td>
<td>5.55 (0.26)</td>
<td>5.53 (0.20)</td>
<td>5.52 (0.23)</td>
<td>5.49 (0.24)</td>
</tr>
</tbody>
</table>

Different from baseline in average 40-m sprint time: *p=0.0002 (ES=0.78, ESCI=0.70 to 0.86), *p<0.0001 (ES=0.83, ESCI=0.75 to 0.91), *p<0.005 (ES=0.62, ESCI=0.54 to 0.70), *p=0.002 (ES=0.72, ESCI=0.64 to 0.79), *p=0.05 (ES=0.49, ESCI=0.41 to 0.57), and *p=0.0007 (ES=0.81, ESCI=0.74 to 0.88); Different from baseline in max 40-m sprint time: *p=0.02 (ES=0.70, ESCI=0.62 to 0.78) and *p=0.002 (ES=0.64, ESCI=0.56 to 0.72); Values are mean (SD)

Table 5 Maximal heart rate and body mass.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal heart rate (bpm)</td>
<td>162.0 (12.4)</td>
<td>162.1 (9.0)</td>
<td>163.4 (13.3)</td>
<td>165.0 (10.8)</td>
<td>163.9 (12.6)</td>
<td>164.1 (11.5)</td>
<td>164.1 (10.6)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>73.4 (6.1)</td>
<td>73.6 (6.2)</td>
<td>74.0 (6.2)</td>
<td>74.0 (6.2)</td>
<td>73.9 (6.0)</td>
<td>73.9 (6.0)</td>
<td>73.9 (6.0)</td>
</tr>
</tbody>
</table>

No differences at any of time point in maximal heart rate (F(5,39)=0.4, p=0.88) and body mass (F(5,39)=0.60, p=0.62)

Values are mean (SD); Body mass was measured at baseline, week 2, 4, and 6.
In conclusion, our results suggest that (1) a sprint training program in which the intensity was 110% of the fastest baseline 40-m sprint time with the addition of one sprint each week produced similar effects to other training programs; (2) based on our training protocol, untrained individuals need at least a 3- to 4-week training period for anaerobic power improvement and strength development in the quadriceps. Subcutaneous tissue thickness reduction of the abdomen and thigh were observed at 2 weeks, and (3) coaches and training personnel can apply interval training with a simple method and less equipment on the field.

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