Maximal Power and Performance during a Swim Taper

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- swim training
- inertial load ergometer
- human performance
- torque

Abstract
This study examined how altering training intensity during a taper impacts maximal mechanical power ($P_{\text{max}}$), torque at power maximum (T), velocity at power maximum (V), and swim performance (m·sec$^{-1}$). Using an arm ergometer with inertial loading, measurements of $P_{\text{max}}$, $T$, and $V$ were made for 7 consecutive weeks prior to the taper and during the taper in 7 female competitive collegiate swimmers. Subjects were tested over two consecutive years. Swim performance was obtained from 3 competitive meets; a conference meet (CM), the conference championship meet (CONF) and the national championship meet (NAT). A 50 to 60% increase in the amount of “high-intensity training” during the taper of 2005 (High-Intensity Taper – HIT) resulted in $P_{\text{max}}$ values that were 8 to 14% higher (40 to 60 Watts) at all but one time point when compared to the 2004 taper (Low-Intensity Taper – LIT). Swim performance was significantly worsened at the NAT following LIT. However, with the HIT, swim performance, $P_{\text{max}}$, and $T$ were maintained prior to and at NAT. A large reduction in high-intensity training during a taper reduces the length of time that $P_{\text{max}}$, $T$, and swim performance can be maintained at peak levels.

Introduction
Prior to major competition athletes commonly taper their exercise training. Generally, a taper can be defined as a period of training lasting a few days to several weeks in which training volume is progressively reduced while a portion of training is maintained at a high intensity [19]. The combination of training volume and training intensity implemented during the taper will depend on the sport and the desired adaptation necessary for successful competition. Swimming is unique when compared to other endurance sports such as running and cycling given that swimmers perform a very large volume of training relative to the demands of their competitions. This model of training may require swimmers to rely heavily upon the taper in order to perform optimally. Despite the widespread use of the taper, little is known regarding how training volume and training intensity impact the time course of adaptations. Following the taper, muscle fatigue is reduced and the positive aspects of physical training such as increased muscular power, strength, and muscle fiber size, as well as improved metabolic and contractile properties of single muscle fibers have been documented [3, 10–14, 17, 20–30, 32]. Previously we reported that the time course for increases in maximal mechanical power during a three-week taper in male collegiate swimmers is biphasic with improvements occurring during the first and third week of the taper [29]. We hypothesize that the improvements in swimming performance during a taper are, in part, due to neurological and muscular factors and that weekly quantification of improvements in maximal power provide insight as to whether the training and taper programs are progressing satisfactorily.

Successful swim performance has been directly linked to the athlete’s ability to generate high mechanical power during a three-week taper in male collegiate swimmers is biphasic with improvements occurring during the first and third week of the taper [29]. We hypothesize that the improvements in swimming performance during a taper are, in part, due to neurological and muscular factors and that weekly quantification of improvements in maximal power provide insight as to whether the training and taper programs are progressing satisfactorily.

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The purpose of this study was to determine how alterations in training intensity during a taper impact maximal arm power and swim performance. In order to answer this question, maximal power was measured during the 7-week period prior to the national championship meet during two consecutive years in a nationally ranked team of female collegiate swimmers. Following the 2004 season, the taper regimen that was performed was deemed unsuccessful by the coaching staff and drastic changes to the taper were made the following year (2005). This investigation is therefore a description of how alterations in training intensity during a taper impact maximal arm power and swimming performance.

**Methods**

**Subjects**

Seven female collegiate swimmers (64.8 ± 2.0 kg, 169.9 ± 1.65 cm, 18.6 ± 0.3 yrs) who each were among the top 40 in the USA (National Collegiate Athletic Association [NCAA] Division I) in their best event, participated in this study. All participants trained and competed in swimming for a minimum of 8 years. The distances and events used to measure performance in this study were the 50 m freestyle (n = 2), 100 m freestyle (n = 1), 100 m breaststroke (n = 1), 100 m backstroke (n = 1) and 200 m individual medley (n = 2). All subjects were members of the University of Texas at Austin women’s intercollegiate athletics swim team and procedures were approved according to guidelines of the Institutional Review Board of the University of Texas at Austin. Each subject was tested during both the 2004 and 2005 seasons. The taper of 2004 was characterized by a low volume of high-intensity training and is referred to as low-intensity taper (LIT), while the taper of 2005 was characterized by a high volume of high-intensity training and is referred to as high-intensity taper (HIT).

**Inertial load ergometry**

The inertial load ergometer for measurement of lower body maximal power during leg cycling, as described by Martin et al. [18], was modified for the measurement of arm power. This was accomplished by removing the seat and mounting a swim bench to the ergometer frame, adding crank handles, replacing the 56 tooth chain ring with a 39 tooth chain ring (gear ratio = 2.7857), and removing the intermediate gear. Flywheel angular velocity and acceleration were determined by an optical sensor and micro-controller based computer interface which measured time (± 1 µsec) and allowed power to be calculated instantaneously every 3 degrees of crank revolution or averaged over one complete revolution of the cranks [18]. All powers expressed in this paper are average values over one complete crank cycle. The inertial load of the ergometer used was 3.65 kgm². As described in Martin et al. [18], maximal power was calculated as the product of moment of inertia, velocity and angular acceleration of the flywheel.

**Inertial load ergometer tests**

All inertial load ergometer testing was performed during the swim training sessions. Testing during the swim training sessions allowed for minimal interruption to the taper and training regimen of the participants. Subjects were randomly rotated out of their normal workout routine by their coach at a time when they were sufficiently warmed up but not too fatigued to perform the power test. Subjects towel dried and placed themselves in a comfortable prone position on the bench with the cranks at forty-five degrees past vertical (zero degrees equals top dead center of crank revolution and one hundred and eighty degrees equals bottom dead center of the crank revolution). Bench height and body position were held constant for each subject. Four trials were performed per subject for most tests. During trials one and three, the subject began with her right arm forward on the crank arm, which was placed at the forty-five degree position. Trials two and four were performed with the left arm forward and the crank arm in the forty-five degree position. Data acquisition for each trial required approximately three to five seconds of maximal effort; therefore, total time spent performing the inertial load test per subject was approximately 5 minutes per week with actual arm cranking of 15 to 20 seconds. Sixty seconds were allotted for a recovery period between trials, which was predetermined to be sufficient to prevent residual fatigue.

**Time course for testing**

Due to the fact that the inertial load ergometer test was a novel task for the subjects, a series of three inertial load tests (total of 12 learning trials) were performed by each subject at least one week prior to the start of data acquisition for the LIT. Testing periods corresponded to a given weekly period of training for each group. Table 1 reports the number of days before each competition that the power test was performed, as well as the number of days before the national championship (NAT) meet that each competition occurred. Each week of the taper is labeled according to the number of weeks prior to competition. For example, week 3 corresponds to three weeks before the conference championship meet (CONF) and week 1 corresponds to 1 week before CONF.

The inertial load measurements were made as close to the start of competition as possible; however, due to travel constraints of the team, the last measurement before NAT occurred 2 days before the start of the CONF meet and the last measurement before NAT occurred 4 days prior to the start of NAT. Measurements of maximal power (P_max), torque at power maximum (T), and velocity at power maximum (V) reported for the period of the taper after the CONF were taken during the first week of this 2 week period and will be referred to as Post-CONF throughout the remainder of this manuscript. Swimming performances, reported as swim velocity (m·sec⁻¹), were obtained via official results from a regular season conference meet (CM), the Big 12 Conference Championships (CONF), and the National Collegiate Athletic Association Championships (NAT). Swimming events, distances, and stroke style used to measure swim performance for each participant were identical for the two years.

**Data calculations**

The two highest powers of a given session were averaged and represent the P_max of the athlete. V and T were calculated by taking the average of the velocities and torques corresponding to the two highest P_max values. Data are reported as absolute values of P_max, T, and V (± standard error of the mean). Mean coefficients of variation (SD/mean) for P_max, V, and T were: 2.38 ± 0.18%, 6.01 ± 0.39%, and 6.31 ± 0.56%, respectively.
Results

Training and taper
The primary difference between the two years during the first three weeks of the taper (prior to the conference meet including week 3, week 2, week 1 of the taper) was the substantially greater volume of training performed at a high intensity (i.e., race pace or effort) during HIT compared to LIT. High-intensity training contributed approximately 30 to 32% of total training load throughout the HIT, while 15 to 20% of the total training load was performed at high intensity throughout the LIT (Fig. 1a and b). The second major difference between the two years was the manner in which training volume and intensity were tapered prior to the national meet (i.e., NAT). After the CONF during HIT (Post-CONF week 2 and Post-CONF week 1; Fig. 1b), the volume of high-intensity training was increased and then tapered. Interestingly, except for the reduced training during the week of CONF competition, the tapering of high-intensity training appeared to follow a progressive and linear reduction during this seven-week period in HIT. During LIT, the volume and intensity of training was kept low and constant over the 2-week period after the CONF (Fig. 1a and b).

Power (Fig. 2)
In order to make comparisons across years, absolute \( P_{\text{max}} \) was compared at corresponding test dates in HIT and LIT. \( P_{\text{max}} \) was 8 to 14% higher at all but one time point (week 2) during HIT when compared to LIT. This indicates that the HIT was superior at maintaining maximal mechanical power. During the first three weeks of HIT (i.e., week 3, 2 and 1), \( P_{\text{max}} \) was significantly increased by approximately 6% at week 2 (396.4 ± 12.6 W, \( p = .007 \)) when compared to week 3 (374.8 ± 16.0 W). The increased \( P_{\text{max}} \) was maintained throughout the first taper period prior to CONF. One week after CONF (Post-CONF), \( P_{\text{max}} \) was reduced by 9% (364.7 ± 13.8 W, \( p = .002 \)). During the HIT, week 3 training was not characterized by reduced \( P_{\text{max}} \) as seen with LIT. Furthermore, \( P_{\text{max}} \) was maintained throughout HIT and tended to be highest at CONF and NAT. \( P_{\text{max}} \) was significantly increased at

Training
Training was comprised of both swim and land-based workouts. Swim training generally consisted of a warm-up, continuous moderate-intensity swimming, followed by higher intensity (race pace and higher effort), and ended with a ‘cool down’ period of slower swimming. High-volume (HV) training was performed during the weeks prior to the initiation of the taper. In general, the HV period consisted of 2 to 3 weeks of training in which total exercise volume was between 45,000 and 55,000 meters per week. During this period, twice daily workouts were performed with a frequency of approximately 2 to 3 times per week with the remaining days consisting of one workout per day. Total time spent training (land-based and in-water) during this HV period was between 25 to 30 hours per week. During the early weeks of the taper periods (i.e., week 3), 10 to 12 total training sessions were performed per week. As the taper progressed, the twice daily workouts were gradually removed from the training program with 6 to 8 training sessions being performed per week from mid-taper to peak. Land based training focused on core and upper body strength and was performed 2 to 3 times per week and was gradually reduced and eventually removed from the training by the second week of the taper. The prescribed training of the subjects was reported by the coaches following the completion of the competitive season; therefore, individual training histories are not reported.

Statistical analysis
Two-way analysis of variance (ANOVA) with repeated measures was performed to test significance differences between trials within one year (i.e., tests within LIT or HIT), as well as for comparisons between similar trials between years (i.e., LIT – week 3 vs. HIT – week 3). Least significance difference test identified the means that were significantly different with \( p < 0.05 \). Correlations were completed using the Pearson product-moment of correlation method.

Table 1  Time of maximal power measurements expressed as days prior to the NAT competition (national championship meet). The corresponding competition or weekly period of training is termed week 3, week 2, week 1, CONF, Post-CONF, and NAT. Swim performance was determined via competition at a conference meet (CM), conference championship (CONF), and national championship meet (NAT)

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Fig. 1a and b
NAT (441.6 ± 15.2 W) when compared to week 2 (406.7 ± 15.2 W, p = .032) for the HIT. This pattern appears to describe a successfully planned and executed taper.

Torque (Fig. 3)
Following CONF in LIT, T was reduced by 14 and 6% at Post-CONF (27.9 ± 2.0 Nm, p = .003) and NAT (29.8 ± 0.7 Nm, p = .016), respectively. Torque during the HIT was increased at CONF (33.3 ± 1.3 Nm) when compared to week 3 (p = .021). Unlike LIT, T was not significantly reduced following CONF in HIT. T was similar during LIT and HIT at all time points prior to and including CONF. There was a trend for increased T at Post-CONF (p = .063) and NAT (p = .068) of HIT when compared to the corresponding test dates of LIT.

Velocity (Fig. 4)
During the LIT, V was increased by 6% at NAT (125.8 ± 3.5 rpm, p = .029) when compared to CONF (118.3 ± 1.6 rpm). During HIT, V did not change significantly at any time point. However, during HIT, V was higher by 12% (p = .04) and 7% (p = .018) at week 1 and CONF when compared to the corresponding test dates of LIT.
Swim performance (Table 2)
With LIT, swim performance was improved with the taper by 5.3% (range: 3.2 to 6.7%) at CONF (1.69 ± 0.09 m/sec) and 4% (range: 2.6 to 7.4%) at NAT (1.67 ± 0.10 m/sec, p = .005) when compared to CM (1.61 ± 0.08 m/sec, p = .001). Swim performance was decreased from CONF (1.69 ± 0.09 m/sec) to NAT (1.67 ± 0.10 m/sec, p = .05) during LIT. During HIT, swim performance was improved by 2.7% (range: 1.8 to 3.8%) at CONF (1.69 ± 0.09 m/sec, p < .001) and 2.3% (range: 1.3 to 3.1%) at NAT (1.68 ± 0.09 m/sec, p = .001) when compared to CM (1.64 ± 0.09). Unlike LIT, performance was similar with HIT at CONF and NAT, indicating that the HIT was effective at maintaining the increased swim performance from the conference to national championship meets. Maximal arm power (P_{max}) was significantly correlated with swim performance (R = .401, p < .001) with approximately 16% of the variation in swim performance explained by differences in P_{max} when plotting values for all seven swimmers at each of the three times of competition.

Discussion
This study is the first to describe, longitudinally in the same subjects, how alterations in the volume of high-intensity exercise training during a taper influence the time course of maximal mechanical power and performance from one year to the next. Furthermore, this study is unique as it studied competitive females during a naturally occurring taper (i.e., not laboratory based) with minimal interruption to the swim training and taper regimen of the participants. The LIT implemented during the 2004 season was deemed unsuccessful based upon the decrease in performance at the national championship meet (NAT) when compared to the conference meet held 3 weeks earlier (CONF). This decrease in performance prompted the coaching staff to change the taper during the following year (2005). A doubling of the amount of high-intensity training throughout the taper of 2005 (HIT) resulted in improved performance during the national meet following HIT compared to LIT. This improved performance was associated with the maintenance of maximal power and torque following HIT and significantly higher maximal arm power during HIT compared to LIT. The total volume of swim training performed during LIT and HIT was remarkably similar (Fig. 1a), allowing us to focus primar-
ily on the effect of exercise intensity during the taper. The primary difference between the two tapers was that during the HIT substantially more high-intensity training was performed. During HIT, approximately 30 to 32% of the training volume was high intensity whereas only 15 to 20% of the training volume was at a high intensity during LIT. It has long been known that high-intensity exercise training is a powerful stimulus for skeletal muscle adaptations [5,9]. Classical work by Dudley et al. [5] showed that only when fast twitch muscles are recruited do they begin to show adaptations from the exercise stimulus. More recently, Gibala et al. [7] demonstrated that in active men as little as 15 minutes of maximal sprint efforts (> 250% VO2max) per week resulted in similar adaptations to exercise performed at 65% of VO2max for 4 to 5 hours per week. This information along with the results of laboratory based tapers [20,22,24] suggests that high intensity and supramaximal efforts (i.e., race pace and greater) during exercise training are important during the taper as total training volume is reduced. However, a large increase in training volume coupled with a substantial amount of high-intensity training may lead to adaptations that negatively impact muscle and performance. Fitts et al. [6] showed that following 10 days of intensified swim training, type II fiber diameter and maximal shortening velocity are reduced. Similarly, Harber et al. [8] demonstrated that 8 weeks of high volume and high-intensity run training reduced the power producing capacity of type I muscle fibers. Therefore, proper periodization of the exercise training program is critical to allow for optimal physiological and performance adaptations in competitive athletes. One possible explanation for the significantly lower Pmax values during most of the LIT may be that the volume of high-intensity training was inadequate, thereby resulting in a failure to promote further gains in skeletal muscle performance leading to suboptimal Pmax and/or reduced torque. Alternatively, the swimming speed of the intervals may have been reduced during the LIT directly resulting in suboptimal physiological adaptations as the appropriate energy system may not have been stressed and specific motor units may not have been recruited with optimal technique [5,20,24]. Likewise, the accumulation of an additional year of exercise training and/or improvements in the ability to recover from training may explain the higher Pmax during HIT. Another possible explanation could be that the training in the weeks leading up to the taper may have a substantial impact on the adaptations that occur during the taper. Prior to the start of the taper, the swimmers performed between 45,000 and 55,000 meters per week of total swim training. Prior to HIT, high-intensity training comprised approximately 32% of the total training volume, very similar to the pattern observed during the taper. Prior to LIT, high-intensity training only comprised 18% of the total training volume. The training history during the high volume period prior to the HIT shows a general pattern of reduced volume and increased intensity, which may explain the significantly better performance of the swimmers prior to the start of the HIT. Despite the better performance prior the start of the HIT, performance was identical at CONF following both HIT and HIT. This indicates that the exercise training prior to and during the first three weeks of the taper (week 3 to CONF) delivered the athletes in similar physical condition. Based on the fact that the swimmers performed equally well at CONF following HIT and HIT, we believe that the ability to maintain swimming performance at HIT – NAT is, in part, due to the modified method of tapering.

The taper is one aspect of physical training that is commonly performed by amateur and elite athletes prior to competition, yet the manner in which the fundamental aspects of physical training (duration, intensity, and frequency) influence the time course of taper adaptations have only begun to be described. Previously [29], we demonstrated that maximal mechanical power is increased in a biphasic manner with approximately 50, 5 and 45% of the total increase in Pmax occurring during the first, second, and third week of the taper. A similar biphasic pattern in Pmax was observed in the female swimmers during the LIT season as Pmax increased from week 3 to week 2, decreased from week 2 to week 1, and again increased from week 1 to CONF (Fig. 2). During both of these biphasic tapers, the duration of the taper was 3 weeks and high-intensity training comprised 15 to 20% of the total training volume. However, it appears that when substantially more high-intensity training is performed (30% of total training volume), the time course is no longer biphasic. Torque, as measured by the inertial load ergometer, is a measure of muscular strength and force development. Based upon the results of this investigation and our previous work [29], it appears that the increase in Pmax is largely due to an increase in torque. This agrees with work by Trappe et al. [28] that showed maximal power when measured before and after the taper occurred at the same contraction velocity (3.28 m/sec). Likewise, following CONF, Pmax showed a significant reduction in both HIT and HIT which coincided directly with the decreases in T. Velocity was not different following CONF when comparing HIT to HIT. This provides further evidence that increasing and maintaining torque during a taper is largely responsible for the observed increase and maintenance in maximal mechanical power. This does not necessarily indicate that a significant increase in the velocity of single fibers is not occurring. Indeed, the velocity of shortening of single fibers has been shown to increase (32 and 67% for type I and type IIa fibers, respectively) during the taper [28]. However, in vivo whole muscle contractile velocity of the arms was not altered by tapering in these same swimmers [28]. It seems that alterations at the single fiber level for maximal velocity may not be expressed as increased velocity when power and velocity are assessed within the in vivo neuromuscular system. Therefore, the increases in maximal power during a taper appear to be expressed mostly through increased torque, which reflects alterations within muscle fibers and/or the ability of the central nervous system to recruit motor units.

Both tapers, HIT and HIT, proved to be effective at increasing in-water swim performance by 2.3 to 5.3%, respectively. This magnitude of increase is to be expected as similar improvements of 1 to 8% have been obtained from studies of competitive runners, cyclists, and swimmers [1,3,10–14,17,19–26,28,29]. Performance was similar at the conference meets (CONF) following HIT and HIT. However, this level of performance was not maintained through the national meet (NAT) during the HIT. Therefore, with the primary goal of delivering the athlete in peak physical condition for the national meet, the HIT was most appropriate for this group of swimmers.

In summary, the HIT proved to be more effective at maintaining maximal power and swim performance at the national championships (NAT) when compared to HIT. It appears that when high-intensity training is reduced to 15–20% of the total training load, the duration that maximal arm power, torque and swim performance can be maintained at peak levels is diminished.
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