Journal of Strength and Conditioning Research, 2006, 20(1), 62–72

Effects of Physical Conditioning on Intercollegiate Golfer Performance

Brandon K. Doan,[1] Robert U. Newton,[2] Young-Hoo Kwon,[4] and William J. Kraemer[3]

[1]The Human Performance Laboratory, HQ USAFA/AHML, U.S. Air Force Academy, Colorado 80840; [2]School of Biomedical and Sports Science, Edith Cowan University, Joondalup, Western Australia; [3]Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut 06269; [4]The Biomechanics Laboratory, Texas Women's University, Denton, Texas 76204.

Abstract. Doan, B.K., R.U. Newton, YH. Kwon, and W.J. Kraemer. Effects of physical conditioning on intercollegiate golfer performance. *J. Strength Cond. Res. 20(1):62–72. 2006.*—This investigation was conducted to determine the effects of a physical conditioning program on clubhead speed, consistency, and putting distance control in 10 men and 6 women National Collegiate Athletic Association Division I golfers. Supervised strength, power, and flexibility training was performed 3 times per week for 11 weeks. Performance tests were conducted before and after the training period. Significant ($p < 0.05$) increases were noted for all strength, power, and flexibility tests from pre- to posttraining of between 7.3 and 19.9%. Clubhead speed increased significantly (1.6%), equating to approximately a 4.9-m increase in driving distance. Putting distance control significantly improved for the men-only group (29.6%), whereas there was no significant difference in putting distance control for the total and women-only groups. Eleven weeks of golf-specific physical conditioning increased clubhead speed without a negative effect on consistency or putting distance control in intercollegiate men and women golfers.

Key Words. clubhead speed, sport-specific conditioning, exercise

Introduction

Golf is a popular and rapidly growing sport. According to recent surveys, there are approximately 26.4 million golfers in the United States and golf is ranked 10th in total participation when compared with all other sports and recreational activities. The total number of golfers in the United States has increased by 10% since 1995 (35).

As golf continues to grow in popularity, it remains one of the few sports that appeal to a very broad segment of society. People of all ages, both genders, and all physical fitness levels are able to enjoy the game. The golf handicap system allows even competition between golfers of all skill levels. Additionally, golf is one of the few individual sports in which a team or opponent is not required for competition; therefore, a very large population of golfers participates in competitive golf. The number of elite golf competitors is also growing, as well as the prize money associated with those competitions.

Similar to most other sports, there are several different ways to achieve better performance in golf: improved technique, enhanced physiological capabilities (strength, power, flexibility, endurance, etc.), improved and individually matched equipment, and improved competition management skills. Researchers, golf professionals, and golfers have spent countless hours researching the mechanics of the golf swing and searching for the optimal way to swing the club (8). Golf equipment companies have also spent significant time and effort improving the golf club and ball and their interactions with each other and individual golfers (47, 54). Less research has been done in conditioning or training the human physiological systems for optimal golf performance, although this may be an important area for investigation because physical capabilities may alter golf performance directly via increased muscle strength and power. Additionally, improved physiological function through training may improve technique because increased strength and flexibility allow more optimal mechanics, as well as longer, more effective practice sessions.

Golf is a bilateral sport and studies using electromyography (EMG) have shown significant activity in a majority of the muscles of the body (49). Despite these findings, until recently, the majority of golfers and golf professionals have thought resistance training to have no positive and possibly negative effects on golf performance. However, in the past several years there has been a resistance-training boom in the golf world.

Several investigators have studied the effects of strength, power, and flexibility training on golf performance (10, 15, 18, 25, 28, 45, 51–53). Golfers involved in these investigations, however, were mostly recreational amateur golfers. Training of these amateur golfers increased clubhead speed by 3 to 7% or driving distance by 10 to 15 yards with no negative effects on accuracy. Strength increases were reported between 5 and 56%, and flexibility improved 7–39%. The positive influence of strength, power, and flexibility training on golf performance in recreational amateurs is clear. However, Jorgenson (1970), using a mathematical model, determined there are two important components in clubhead speed: the amount of torque supplied by the golfer and the skill with which the golfer manages the torque (19). Additionally, measurable performance gains and adaptations require more intense training in highly skilled versus novice athletes (13) and estimated gains in novice performance may not apply to elite athletes (16). The influence of strength, power, and flexibility training on elite men and women golfers requires investigation.

The effects of resistance training on consistency or putting distance control have not been studied. Resistance training will improve muscular strength and local muscular endurance (1), which may have an impact on golf swing consistency during an 8-hour, 36-hole round of competitive golf in which 130 or more golf shots may be executed. Consistency is an important factor in a target-

TABLE 1. Strength study subject demographics (values are mean and *SD*).

	Age (yrs)	Weight (kg)	Height (cm)	Competitive scoring average (strokes per 18 holes)
Men (*N* = 10)	19.8 (1.7)	74.5 (9.0)	178.8 (5.6)	76.0 (±1.4)
Women (*N* = 6)	18.5 (0.8)	63.5 (4.1)	169.5 (3.9)	89.0 (±2.2)
Total (*N* = 16)	19.3 (1.5)	70.5 (6.2)	175.3 (6.8)	80.4 (±6.6)

oriented individual sport such as golf in which the player does not have to react to a moving ball or competitor. The purpose of this investigation was to study the effects of a physical conditioning program (strength, power, and flexibility training) on clubhead speed, putting distance control, and consistency in elite collegiate men and women golfers.

METHODS

Experimental Approach to the Problem

The experimental design was a longitudinal training intervention in which the adaptations in neuromuscular function, golfball launch conditions, and putting distance control were assessed in response to a strength, power, and flexibility training program. All subjects were tested before and after 11 weeks of training. Percent change in neuromuscular function and golf club and ball launch conditions were measured after 11 weeks of training. All testing and training was completed in the university biomechanics laboratory, the university athletic weight room, and a local indoor golf driving range.

One weakness of this investigation is that there was not a control group. Because the hypothesis was that the conditioning program would improve performance, it was not ethical to exclude part of the team from it. Additionally, there were not enough collegiate golfers on the university teams to allow adequate statistical power if part of the teams were used as a control group.

Subjects

Subjects included 10 men and 6 women varsity golf athletes (Table 1). The Institutional Review Board of the university approved the investigation. Subjects were fully informed of the purpose and risks of participating in this investigation and signed informed consent documents prior to testing.

For the purpose of this investigation, competitive scoring average for each individual was an average of all competitive golf rounds for a 1-year competitive golf season. Most of these collegiate players did not maintain an official United States Golf Association handicap. However, for comparison purposes to other investigations reporting only handicaps, estimated average handicaps for subjects in this investigation is zero for the men and between 5 and 10 for the women.

Training Protocols

All subjects completed the same golf-specific resistance-training program and it was supervised by certified strength and conditioning specialists. A thorough needs analysis was conducted to ensure specificity of the training program. A more optimal approach would be to tailor the conditioning program to each individual. However, for the purposes of this investigation, the conditioning program was generalized to the entire group of subjects. The training program lasted 11 weeks (see Tables 2–4). A certified strength and conditioning coach supervised the first 2 and last 6 weeks of training. Qualified supervision during strength training sessions is important because greater maximal strength gains have been noted in supervised versus unsupervised training (30). Because of a university holiday, the middle 3 weeks of training were con-

TABLE 2. Flexibility program.*

Program A	Program B
Neck rotation	Lateral neck stretch
Posterior shoulder stretch	Shoulder blade spread
Chest stretch	Side lying trunk stretch
Trunk forward flexion	Sitting knee to opposite shoulder
Trunk rotation	Hamstring stretch
Trunk side bend stretch	Hands/knees back arch and sage

* Stretches completed at end of strengthening program. Adapted from Jobe et al., 1994.

TABLE 3. Preseason strength and conditioning program.

Exercise	Sets × reps (wk 1–5)	Sets × reps (wk 6–11)
Monday		
*Trunk routine		
Incline bench press	3 × 10–12	3 × 7–9
Bent arm pullover	3 × 10–12	3 × 7–9
Machine upright row	3 × 10–12	3 × 7–9
Leg curl	3 × 10–12	3 × 7–9
Back extensions	3 × 10–12	3 × 7–9
Dumbbell step-ups	3 × 10–12	3 × 7–9
Med. ball speed rotations	2 × 15 secs	3 × 15 secs
Med. ball standing throws	2 × 10	4 × 8
Wednesday		
*Trunk routine		
Bench press	3 × 10–12	3 × 7–9
Low cable row	3 × 10–12	3 × 7–9
Dumbbell military press	3 × 10–12	3 × 7–9
Leg curl	3 × 10–12	3 × 7–9
Seated good mornings	3 × 10–12	3 × 7–9
Parallel squat	3 × 10–12	3 × 7–9
Med. ball speed rotations	2 × 15 secs	3 × 15 secs
Med. ball seated throws	2 × 10	4 × 8
Friday		
*Trunk routine		
Dumbbell bench press	3 × 10–12	3 × 7–9
One arm dumbbell row	3 × 10–12	3 × 7–9
Dumbbell shoulder circuit	3 × 10–12	3 × 7–9
Dumbbell lunges	3 × 10–12	3 × 7–9
Leg extensions	3 × 10–12	3 × 7–9
Back extensions	3 × 10–12	3 × 7–9
Wrist curls	3 × 10–12	3 × 7–9
Med. ball speed rotations	2 × 15 secs	3 × 15 secs
Med. ball standing throws	2 × 10	4 × 8

* See Table 4 for trunk routine.

Table 4. Trunk strengthening program.

Exercise	Week 1–2 Sets	Week 1–2 Reps	Week 3–4 Sets	Week 3–4 Reps	Week 5–6 Sets	Week 5–6 Reps	Week 7–8 Sets	Week 7–8 Reps
Monday								
Bent knee crunches	1	20	1	20	2	20	2	25
			1	15				
Back crunches	1	15	1	15	2	15	2	20
			1	12				
Straight leg crunches	1	25	1	25	2	25	2	30
			1	20				
Wednesday								
Isometric pillar bridges	2	30	2	30	2	35	2	40
Friday								
Jackknife opposites	1	24	1	12	2	12	2	15
			1	10				
Russian twists	1	24	1	12	2	12	2	15
			1	10				
Alternate toe touches	1	15	1	15	2	15	2	20
			1	10				
Back crunch with twist	1	12	1	12	2	12	2	15
			1	10				

ducted away from campus and were unsupervised. Athlete compliance during the supervised training sessions was 100%. Some scheduled workouts were missed; however, workouts were individually made up so that all athletes completed the required total number of workouts. Each athlete maintained a training log and the strength coach adjusted the weights for following workouts if the athlete failed outside the specified repetition range to ensure progressive overload.

Recent research has documented the value of stretching alone and in combination with strength training for improved golf performance (18, 53). Investigators have also reported the importance of maximizing the shoulder-to-trunk rotation relationship at the top of the backswing (5). Based on EMG research, Jobe and colleagues (1994) formulated a stretching program for golfers (17). They recommended exercises focused on stretching shoulder and trunk musculature (Table 2). Stretches were completed at the end of the strengthening program. Two sets of each exercise were held at the end of range of motion for 15 seconds. Programs A and B alternated every other workout.

The training program was performed 3 times per week (Monday, Wednesday, and Friday) and lasted approximately 90 minutes per session. Trunk strengthening exercises were performed at the beginning of each exercise session (Table 4). Next, the resistance-training program was completed (Table 3) followed by the stretching program (Table 2). Subjects were also required to practice supervised golf-specific skills (hitting balls at a driving range and putting) for a minimum of 8 hours per week during the training.

Medicine Ball Training Description. For standing throws, subjects took their normal golf stance and posture holding a 2- to 4-kg medicine ball with arms maximally extended in front of them as if holding a golf club. They swung the ball back to just short of their normal golf back-swing position and swung it through the normal impact position, throwing it to a partner a comfortable distance away or into a solid wall or target, while mimicking the golf swing motion. Subjects were instructed to explosively throw the ball at maximal velocity. Subjects switched directions with their partner after 10–15 repetitions and repeated the exercise in the opposite direction. Catching the ball in the same position may also have provided some forced eccentric or stretch-shortening cycle training effect.

For seated throws, to maximize torso-to-hip stretch and isolate torso power, subjects were seated on the floor holding a 2- to 4-kg medicine ball with arms maximally extended in front of them. They were instructed to explosively throw the ball at maximal velocity into a wall or to a partner. Subjects switched directions with their partner after 10–15 repetitions and repeated the exercise in the opposite direction. Catching the ball in the same position may also have provided some training effect.

In medicine ball speed rotations, 2 subjects were seated or standing back to back about 0.5 m apart on the floor. They were instructed to pass a 2- to 4-kg medicine ball behind their back to each other while concentrating on keeping their arms extended and rotating their trunk as quickly as possible. Subjects switched directions with their partner after 15 seconds and repeated the exercise in the opposite direction.

Testing Protocols

Strength Testing. Each athlete was very familiar with the exercises used in the strength testing. The 1 repetition maximum (RM) bench press was determined using previously described methods (21). Immediately prior to each strength testing session, the subjects warmed-up with 2 sets of 8 repetitions at 30–50% of their estimated 1RM. Subjects were allowed adequate rest (2–3 minutes) between warm-up sets and maximum attempts. The bench press and squat testing was completed on standard Olympic benches and squat racks with Olympic bars and weights. The shoulder press was completed using dumb bells and the lat pull using a Universal lat pull cable machine. For the squat, shoulder press, and lat pull down exercises, each athlete performed a set to failure and the strength was estimated using the Brown equation to calculate a predicted 1RM (27).

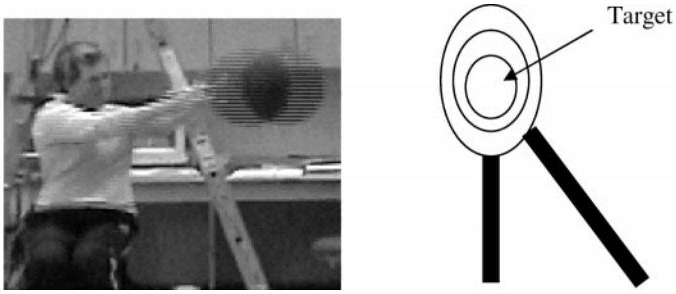

FIGURE 1. Medicine ball rotational put test. Videotaped at 240 Hz, leading edge of ball digitized, and resultant velocity at release calculated. Line drawn at starting position.

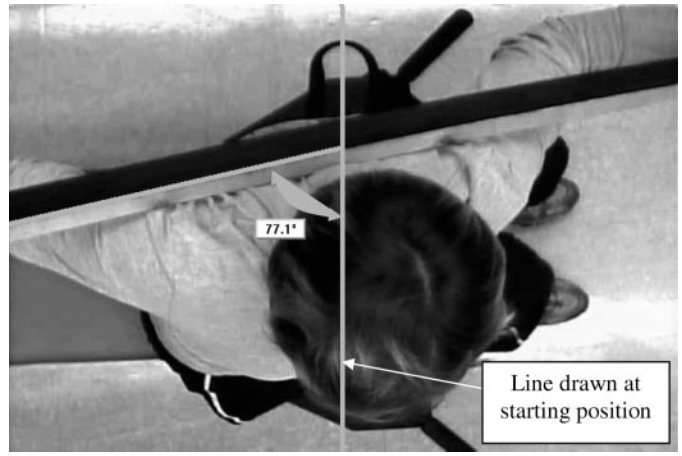

FIGURE 2. Trunk rotation flexibility test. Angle between starting position and maximal rotation measured using Swinger computer software. Three trials in each direction averaged for statistical analysis.

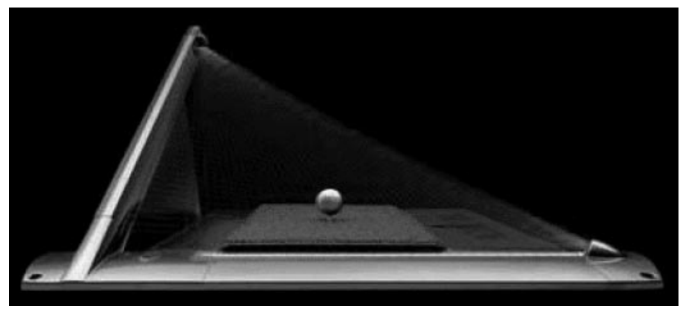

FIGURE 3. GolfAchiever.

Isometric handgrip strength testing was performed using a Jaymar model 30J4 (Country Technology, Gays Mills, WI) handgrip dynamometer. The dynamometer was adjusted to the subject's hand. Subjects were instructed to fully extend at the elbow, raise the arm to 90 degrees of shoulder flexion, and maintain 0 degrees of wrist extension to ensure consistency between conditions. Three maximal trials were used for warm-up and familiarization. The mean of 3 maximal trials from the left hand was used in data analysis (58).

Subjects were tested on rotational trunk power by throwing a 2-kg medicine ball into a target. The subject was seated on a weight-training bench with legs and hips secured to the bench with Velcro straps. Target height was set at the same height as release so flight would be horizontal. Trials in which the ball did not hit the target were discarded. Each throw was videotaped with a JVC 9800 digital videocamera (JVC Americas Corp., Wayne, NJ) at 240 frames per second.

The video was subsequently captured using a Marvel video capture card, edited in Adobe Premiere 5.1 computer software, and digitized and analyzed using Kwon 3D (version 3.0, Visol Inc., Seoul, Korea) motion analysis software. Four points of a calibration frame were digitized prior to digitizing each videotaping session. The leading edge of the ball was digitized for several frames before and after ball release. Raw digitized coordinates were filtered using a 6 Hz, second-order Butterworth low-pass filter and converted to real-world coordinates using 2-dimensional direct linear transformation (DLT) (48). Velocity at ball release was then calculated and 3 trials were averaged for statistical analysis (Figure 1).

Flexibility Testing. Maximum trunk rotation in both directions was measured using video analysis. A videocamera was centered above the subject's head. The subject was seated on a weight-training bench with legs and hips secured to the bench with Velcro straps. Subjects placed a 1-m long board across their shoulders and were instructed to rotate their trunk to the end of their range of motion and hold for 3 seconds. Three trials were recorded for each subject in both directions and averaged for analysis.

The video was subsequently captured using a Matrox Marvel (Matrox Inc., Quebec, Canada) video capture card, edited in Adobe Premiere 5.1 computer software (Adobe Systems Inc, San Jose, CA) and then analyzed using Swinger computer software (Webbsoft Technologies, Victoria, Australia). Swinger allowed lines to be drawn parallel to the shoulders at a neutral trunk position and at maximum trunk rotation. Swinger then computed the angle in degrees between the lines. Three trials were then averaged for each subject to come up with a clockwise (back-swing direction) and counterclockwise (follow-through direction) trunk-rotation mean (Figure 2).

Golfball Launch Conditions. Subjects warmed up by taking practice swings and hitting at least 15 golf balls within the testing area. For testing, subjects hit 15 new golf balls of the same brand and compression with their own driver. Each subject used the same driver, tee height, and golf balls for pre- and posttesting. Golfball launch data was collected for each trial with a GolfAchiever (Focaltron Corp., Sunnyvale, CA) golf swing and ball launch condition analyzer connected to a laptop computer (Figure 3). The GolfAchiever uses solid-state semiconductor laser technology to capture ball and club information in detail. To discount mishits, the 5 best drives for each subject were averaged for clubhead speed statistical analysis. However, all 15 drives were used to compute standard deviations for face and launch angles as a measure of consistency.

Three variables were collected and used for statistical analysis: clubhead speed, clubface angle, and launch angle. Clubhead speed is the linear speed of the clubhead when it impacts the ball, which is a main determinant of the distance the golf ball will travel (6). Clubface angle is the angle of the clubface at impact. An open or closed clubface (in relation to swing path and target line) will cause the ball to start off line and spin and curve further of line, depending on the club path and clubface angle

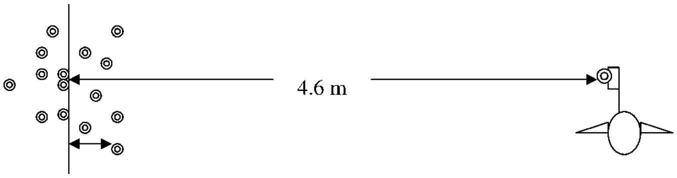

FIGURE 4. Putting distance control test. Putting score = average perpendicular distance from each ball to target line for 15 putts.

relationship. Launch angle is the take-off angle of the golf ball relative to horizontal. Launch angle will have an effect on the trajectory and overall distance the golf ball travels (56).

Qualitative Video Analyses. The last 3 swings for each subject during the 15-swing launch condition testing session were recorded in the frontal view using a JVC 60 Hz VHS-C videocamera (Model GR-AX76). This order was chosen to conserve time and videotape during data collection and there was little deviation expected between trials due to the high skill levels of the golfers. Shutter speed was set at 1/2,000 of a second. Qualitative analysis for each subject was performed using Swinger computer software to overlay pre- and posttraining swing images and identify changes in critical swing elements from pre- to posttesting.

Putting Distance Control Tests. There are 2 key elements to putting—distance and direction. Distance control, or touch, has been identified as the more difficult and important element to successful putting (38). Subjects putted 15 balls to a line perpendicular to the intended direction of the ball 4.6 m from the starting position on an indoor putting green (Figure 4). The putt was straight and flat. Mean deviation from the perpendicular line for all putts was measured for each trial and compared between time points. Subjects putted a minimum of 5 practice putts prior to testing and completed a total familiarization trial of 15 putts 2–4 days prior to the pretesting session.

Statistical Analyses

A 2-way analysis of variance (ANOVA) with repeated measures was used to analyze the data and determine any pre- and posttraining differences in the sample distributions. Pearson product-moment correlation coefficients were calculated to determine bivariate relationships between selected dependent variables. Significance in this investigation was defined as $p \leq 0.05$.

All testing was performed at the 0.05 confidence level. The primary goal of the study was to determine whether there was a difference in the change between pre- and postimplementation of a physical conditioning program. Consequently, our power analysis was based on the specific post hoc comparisons of the 2 conditions for the entire sample. The sample of 16 complete data sets provided a 96% chance (power) of detecting a difference that is about 1 standard deviation of the difference in magnitude (i.e., effect size of 1.0).

RESULTS

For all groups, all strength, power, and flexibility measures significantly increased between pre- and posttraining time points (Table 5). For the entire group, clubhead speed increased significantly between pre- and posttraining, whereas putting distance control deviation decreased significantly for the men. Face and launch angle did not change significantly from pre- to posttraining (Table 6).

TABLE 5. Summary of the effects of the physical training program on strength, power, and flexibility.

Variable		Pre		Post		Post-pre		%	
		Mean	*SD* ±	Mean	*SD* ±	Mean	*SD* ±	Change	*p* value
Trunk rotation flexibility–back-swing direction (cw) (degrees)	Total*	74.39	9.53	85.41	8.92	11.02	6.24	14.82%	0.000
	Women*	75.44	11.22	87.77	8.99	12.33	6.22	16.35%	0.005
	Men*	73.69	8.88	83.83	9.04	10.15	6.47	13.77%	0.002
Trunk rotation flexibility–follow-through direction (ccw) (degrees)	Total*	73.44	7.68	80.57	10.42	7.13	6.73	9.71%	0.001
	Women*	75.87	4.84	81.64	5.15	5.77	3.46	7.61%	0.009
	Men*	71.82	9.00	79.86	13.11	8.04	8.34	11.19%	0.02
Grip strength (N)	Total*	39.60	10.12	42.49	11.51	2.89	3.04	7.29%	0.005
	Women*	29.31	3.32	31.56	3.87	2.25	2.06	7.68%	0.043
	Men*	46.46	6.31	49.78	8.54	3.31	3.61	7.13%	0.026
Bench press 1 RM† (kg)	Total*	59.41	25.4	65.46	23.72	6.05	4.82	10.18%	0.000
	Women*	37.41	7.7	44.97	9.23	7.56	5.68	20.20%	0.022
	Men*	74.07	22.0	79.11	20.17	5.04	4.21	6.80%	0.007
Squat 1 RM (kg) (estimated from 4–6 RM)	Total*	81.79	28.12	92.65	27.34	10.85	7.50	13.27%	0.000
	Women*	50.79	9.29	61.68	8.98	10.88	6.08	21.43%	0.016
	Men*	99.02	17.53	109.9	15.55	10.83	8.54	10.94%	0.005
Lat pull 1 RM (kg) (estimated from 6–10 RM)	Total*	79.79	7.04	89.85	22.81	10.06	4.14	12.61%	0.000
	Women*	53.29	2.38	65.38	5.99	12.09	3.10	22.70%	0.000
	Men*	95.69	5.83	104.5	14.44	8.84	4.34	9.24%	0.000
Shoulder press 1 RM (kg) (estimated from 6–10 RM)	Total*	18.75	7.04	23.16	6.73	4.21	2.79	23.56%	0.000
	Women*	12.47	2.38	17.01	3.44	4.54	3.51	36.36%	0.025
	Men*	22.93	5.83	27.78	4.33	3.97	2.35	21.15%	0.002
Medicine ball throw velocity (m/s)	Total*	5.81	0.55	6.96	0.77	1.15	0.66	19.87%	0.000
	Women*	5.35	0.46	6.28	0.70	0.93	0.53	17.30%	0.009
	Men*	6.06	0.42	7.34	0.53	1.28	0.72	21.14%	0.001

* A significant ($p < 0.05$) difference was observed between pre and post conditions.
† RM = repetition maximum.

TABLE 6. Summary of the effects of the physical training program on golf performance.

Variable		Pre Mean	Pre *SD* ±	Post Mean	Post *SD* ±	Post-pre Mean	Post-pre *SD* ±	% Change	*p* value
Clubhead speed (m/s)	Total*	47.27	3.77	48.04	3.01	0.76	1.43	1.62%	0.029
	Women	43.45	2.48	44.91	1.59	1.46	1.61	3.36%	0.077
	Men	49.82	1.66	50.17	1.42	0.30	1.16	0.61%	0.423
Face angle standard deviation (degrees)	Total	2.19	0.78	2.21	0.40	0.02	0.55	1.10%	0.515
	Women	3.13	0.19	2.68	0.45	−0.46	0.30	−14.57%	0.123
	Men	1.79	0.52	2.02	0.15	0.23	0.51	12.89%	0.281
Launch angle standard deviation (degrees)	Total	2.25	0.54	1.98	0.71	−0.27	1.22	−11.96%	0.317
	Women	2.42	0.67	2.32	0.74	−0.10	0.83	−4.21%	0.332
	Men	2.14	0.45	1.73	0.61	−0.41	1.47	−19.12%	0.244
Putting distance control-15 ft putt (cm)	Total	26.87	6.39	21.38	7.14	−5.49	9.42	−20.44%	0.064
	Women	28.69	7.8	26.74	8.42	−1.95	12.36	−6.79%	0.709
	Men*	25.79	5.41	18.16	3.86	−7.62	7.05	−29.56%	0.007

* A significant ($p < 0.05$) difference was observed between pre and post conditions.

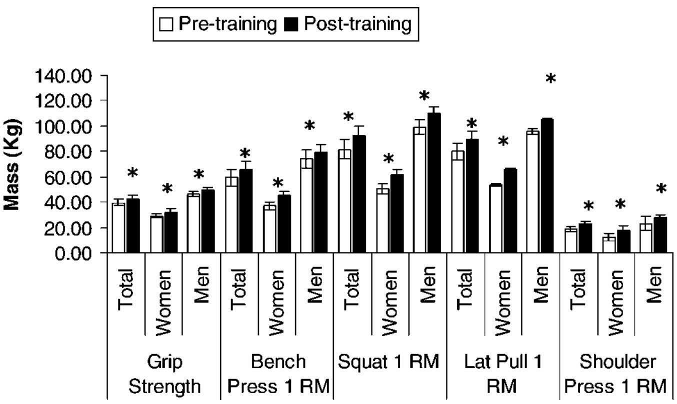

FIGURE 5. Strength measures for pre- and posttraining. Values are means (± *SE*). A significant ($p < 0.05$) difference was observed between pre- and posttraining conditions for all exercises.

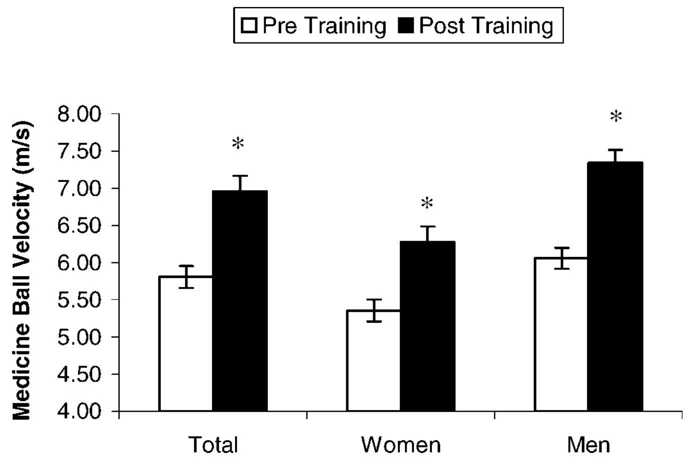

FIGURE 6. Rotational power (medicine ball put release velocity) means (± *SE*) for pre- and posttraining. A significant ($p < 0.05$) difference was observed between pre- and posttraining conditions.

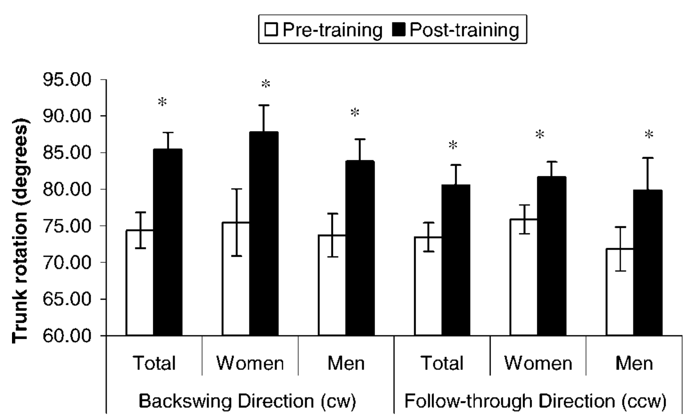

FIGURE 7. Trunk flexibility means (± *SE*) for pre- and posttraining. A significant ($p < 0.05$) difference was observed between pre- and posttraining conditions.

Strength Testing

As hypothesized, grip strength, bench press 1RM, estimated squat 1RM, estimated lat pull 1RM, and estimated shoulder press 1RM were all significantly greater for all groups following the 11 weeks of strength training (Figure 5).

Rotational Power

As hypothesized, rotational power, measured as medicine ball put release velocity, was significantly greater for all groups following the 11 weeks of strength, power, and flexibility training (Figure 6).

Flexibility Testing

As hypothesized, trunk rotation flexibility in the backswing and follow-through direction was significantly greater for all groups following the strength, power, and flexibility training protocol (Figure 7). A summary of the effects of the physical training program on strength, power, and flexibility is provided in Table 5.

Qualitative Video Analysis

A qualitative analysis of each subject's golf swing did not indicate any consistent trends in alteration of important swing mechanics from pre- to posttraining. No obvious swing changes were noted in 3 of the women and 2 of the men subjects. Two of the women subjects appeared to have a greater transfer of weight from nontarget to target foot in post- compared with pretraining swings, whereas 1 of the men appeared to have a greater transfer of weight from nontarget to target foot in pre- compared with posttraining swings. One of the women maintained a more

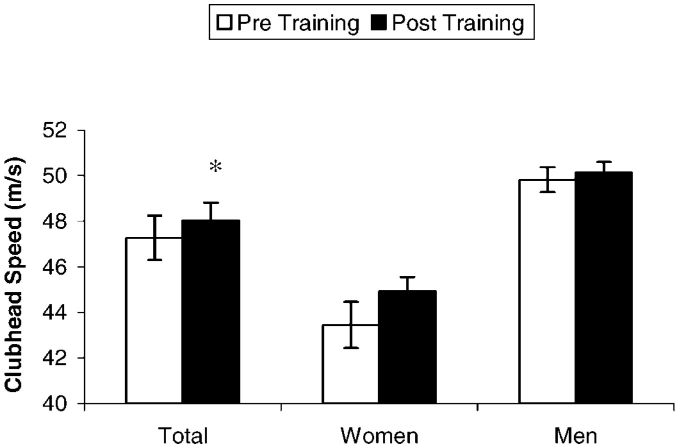

FIGURE 8. Clubhead speed means (± *SE*) for pre- and posttraining. A significant ($p < 0.05$) difference was observed between pre- and posttraining conditions.

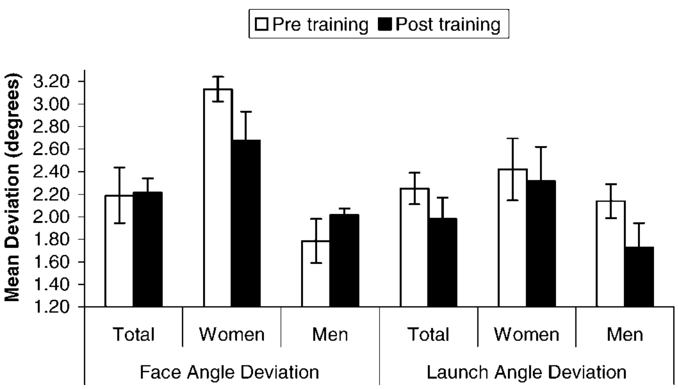

FIGURE 9. Launch and face angle deviation means (± *SE*) for pre- and posttraining.

extended right arm during take-away and a greater "x-factor" (5), or difference between hip and shoulder rotation at the top of her back swing during the posttraining video session. One of the men decreased extension of the right arm during take-away from pre- to posttraining. Two of the men appeared to release the club later (allow the wrists to uncock later) in the pre- compared with the posttraining video session. One of the men had a decreased "x-factor" in the post- compared with the pretraining video session. Another one of the men maintained a better synchronization between his trunk rotation and arm swing in post- versus pretraining swings. His arms lagged further behind his trunk in the pretraining swings.

Golf-Ball Launch Conditions

As hypothesized, clubhead speed for the entire group was significantly higher following the training period (Figure 8). However, there were no significant differences between pre- and posttraining clubhead speeds for the men-only or women-only groups. Contrary to our hypothesis, no significant differences were demonstrated between pre- and posttraining values for face-angle deviation or launch-angle deviation for the total, men-only, or women-only groups (Figure 9).

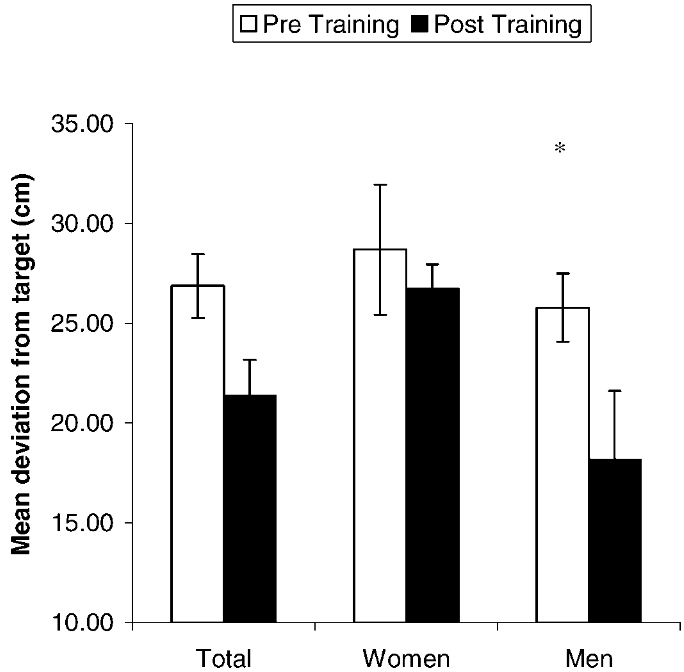

FIGURE 10. Putting distance control means (± *SE*) for pre- and posttraining. A significant ($p < 0.05$) difference was observed between pre- and posttraining conditions.

Putting Distance Control Test

Contrary to our hypothesis, there was no difference between pre- and posttraining putting test values for the total group and the women-only group. However, the men-only group posttraining putting test score was significantly lower than the pretraining putting score, indicating better putting distance control performance following the training (Figure 10). Table 6 provides a summary of the effects of the physical training program on golf performance.

Correlations Between Measures

Pearson product-moment correlation analysis between golf performance, strength, power, and flexibility measures for each group by gender resulted in only one significant ($p < 0.05$) correlation between measures. Clubhead speed was significantly correlated to medicine ball put velocity ($r = 0.86$).

DISCUSSION

The primary finding in this investigation is that clubhead speed in a group of men and women collegiate golfers increased following 11 weeks of strength, power, and flexibility training from 47.3 to 48.0 m·s, without a negative impact on consistency or putting distance control. If all other impact variables were held constant, this 0.7 m·s increase in clubhead speed equates to approximately a 4.9-m increase in driving distance (6). Increased driving distance allows shorter, more accurate, iron shots to be hit into the greens and is an important ingredient in overall golf performance. Driving distance has been positively correlated with score in average golfers ($r = 0.64$) (41) and elite golfers ($r = 0.49$ to $r = 0.84$) (14). In a statistical comparison of performance variables for the 1995 Professional Golfers' Association (PGA) Tour, only driving distance and total driving (distance and accuracy) measures were significantly different ($p < 0.05$) between the top and bottom 10 money winners (9). Cochran and colleagues (1968) studied the performance of a group of professional golfers playing in a professional tournament (6). They concluded that a 17-m increase in driving distance, with no change in accuracy, would result in an improvement in golf score of 2.2 strokes per 18-hole round. Comparatively, the approximately 4.9-m increase in driving distance noted in this investigation would equate to a 0.63 improvement in golf score per 18-hole round. PGA Tour players would improve 72-hole tournament scores by 2.54 strokes, equating to a greater than $20,000 increase in tournament winnings or a greater than $500,000 increase in annual earnings over a 25-tournament season (31).

Mechanisms possibly responsible for the motor performance adaptations following the training program may be related to greater activation and synchronization of higher recruitment threshold motor units or enhanced inhibition of antagonist muscle activity following resistance training (43). Other possible mechanisms contributing to the increased clubhead speed include increased muscle strength, increased rate of force development, increased velocity of muscle contraction, reduction of strength imbalances, increased flexibility, or more optimal mechanics (23). Further research is required to directly relate specific mechanisms to changes in motor performance.

Several previous studies have noted increases in clubhead speed or distance of 4–7% following resistance and flexibility training (15, 18, 25, 28, 45, 51–53). However, the clubhead speed increased only 1.62% in this investigation. There are several possible explanations for the smaller relative gains in clubhead speed in this investigation.

The higher skilled golfers participating in this investigation may respond differently to strength, power, and flexibility training than recreational amateur golfers. Measurable performance gains and adaptations require more intense training in highly skilled versus novice athletes (12, 13, 44) and gains in novice performance may not apply to elite athletes (16). Jorgenson (1970), using a mathematical model, determined there are 2 important components in clubhead speed: the amount of torque supplied by the golfer and the skill with which the golfer manages the torque (19). Strength, flexibility, and power gains may allow and encourage more optimal swing mechanics in novice players, whereas skilled players have already refined mechanical methods. Further study is required to investigate the differential effects of physiological adaptations on skilled and novice golfer's mechanics.

Differences in training programs used in the current versus previous investigations offers one possible explanation for differences in clubhead speed changes. However, key training program variables, such as the total length, volume, specificity, and intensity (3) of the training program, used in this investigation were at least as high as training programs of previous investigations. Length of previous programs ranged from 8 to 12 weeks, whereas volume and intensity ranged from 1 to 3 sets of 8–12 repetitions. Additionally, previous investigations did not include rotational power training, which was included as part of the training program for this investigation. One investigation documented increased gains in baseball bat speed when medicine ball rotational put training was combined with traditional resistance training programs (29). Finally, all strength and power measures were significantly higher following the training program in this investigation (Table 6; Figure 5). Relative strength (7–24%) and flexibility (7–16%) gains in this investigation were similar to previously reported strength (5–56%) and flexibility (7–39%) gains (15, 18, 25, 28, 45, 51–53). Therefore, there must be another explanation for the lower relative gains in clubhead speed noted in this investigation.

One confounding variable may be the volume of golf skills training. For this investigation, the strength, power, and flexibility training was conducted during the offseason. Although subjects were required to practice golf-specific skills a minimum of 8 hours per week during the training, this may not have been enough to prevent a related decrease in golf performance. Initial testing was conducted 2 to 3 weeks following the regular season. During the regular season, golfers were required to practice and play golf 5 days per week for a minimum of 20 hours per week. Most previous studies were conducted with less skilled golfers whose volume of golf-specific training may not have decreased, or possibly even increased, during the resistance training. Further study is required to investigate the effects of the volume of golf-specific training on golf performance.

Another interesting finding in this investigation is that, although there was no significant change in clubhead speed from pre- to posttraining when the group was separated by gender, the women showed a greater trend toward an increase (3.36%) compared with the men (0.61%) from pre- to posttraining. The effect size for the women-only group was 0.72, indicating that with a larger sample size the increase in clubhead speed following training may have been significant (46). All 6 women increased clubhead speed from pre- to posttraining, whereas only 7 of the 10 men increased clubhead speed.

There are several possible explanations for these results. Although the men and women participated in identical physical conditioning programs, the women made greater relative strength gains in the bench press (men = 7%, women = 20%), squat (men = 11%, women = 21%), lat pull (men = 9%, women = 23%), and shoulder press (men = 21%, women = 36%). Both gender groups were recently (past 6 months) untrained; however, most of the men had some type of background in resistance training, whereas 5 of the 6 women did not. Subjects with no background in resistance training may have had a wider window of adaptation for strength increases.

Another possibility for seemingly greater response in clubhead speed in women subjects in this investigation is that the women were at a lower relative skill level than the men. The women's team was in its first year and most of the players were freshmen. According to end-of-season Golfweek rankings, the women's team was ranked 170th out of 197 (the 14th percentile) National Collegiate Athletic Association (NCAA) Division I women's golf teams, whereas the men were ranked 132 out of 286 (the 54th percentile) NCAA Division I men's golf teams (2). The increase in strength and flexibility may have allowed the women to adopt more optimal swing mechanics, whereas the men already used closer to optimal swing mechanics. However, no consistent trends were noted in either group when comparing pre- and posttraining swings using qualitative analysis.

Lastly, men have significantly more overall, and especially more upper-body, strength than women (26). Because of the short duration of the downswing in golf (0.3 seconds), maximal force values cannot be generated. Men would have a larger explosive strength deficit (difference between maximal force and forces generated in the downswing), which may reduce the effectiveness of maximal strength training. The women's explosive strength deficit may have been lower, increasing the value of maximal strength training to increasing clubhead speed (57). Additionally, the slower contraction velocities used in resistance training movements may not increase power production capabilities, especially in trained subjects (12, 20, 55). Because golf requires high power outputs, more high-velocity exercises may have caused more golf-specific adaptations.

Consistency in this investigation was measured as the standard deviation of golfball launch and clubface angle for 15 driver shots. There was no change in these measures from pre- to posttraining. It is important to note that, in general, no negative effect on consistency resulted from the training. A more fatiguing consistency protocol, such as increased number of swing repetitions, walking interspersed between shots, or collecting data following a competitive round of golf, may reveal different results.

The effect of specific swing elements on clubhead speed or golfball launch conditions has not been investigated. However, several studies have compared novice players with experts and correlated different swing elements to clubhead speed (42). No common trends in swing mechanics alteration from pre- to posttraining were noted in the qualitative analysis. Individual golf swings and specific adaptations to resistance training are variable. Small, consistent differences in technique from pre- to posttraining may have existed. However, limitations in camera angle, frame-rate and shutter speed may have resulted in the qualitative video analysis being insufficiently sensitive to detect them. The interaction of swing mechanics and strength training is interesting and requires further study. A high-speed 3-dimensional motion analysis of golfers before and after a strength-training program would provide a more sensitive quantitative analysis of swing alterations and possibly detect changes due to increases in strength, flexibility, and muscle size.

Putting distance control significantly improved from pre- to posttraining for the men-only group (29.6%). There was a trend toward improved putting distance control in the total (20.4%) and women-only (6.8%) groups; however, differences were not statistically significant. Two possible mechanisms for this improvement in putting distance exist. First, the strength training induced increase in muscle strength may have allowed more postural stability and less variation in putting distance control. Second, improvement in motor unit recruitment and firing patterns has been noted with resistance training, which may improve regulation of force (4). This is an important finding because an average of 40% of all golf shots in an 18-hole round are putts (11).

Pearson product-moment correlation analysis among golf performance, strength, power, and flexibility measures for each group by gender resulted in only one significant correlation. In the men-only group, medicine ball put velocity was correlated with clubhead speed ($r = 0.86$, $p < 0.05$). This result is not surprising because the medicine ball rotational put closely matches the speed and movement pattern of the golf swing. The angular velocity of the arms (9.3 radians·s) for the men during the medicine ball puts in this investigation is similar to angular velocity values reported for the arms at impact during male collegiate player golf swings (33). When medicine ball rotational put exercises were added to a resistance-training program for collegiate baseball players, bat speed significantly improved when compared with a resistance–training-only control group (29). Similarly, investigators have reported greater gains in vertical jump when ballistic training is performed in conjunction with traditional resistance training (32). These results are also in agreement with EMG investigations that have noted high trunk muscle activation during golf swings (39). It is apparent that ballistic rotational put exercises should be included in golf-specific physical conditioning programs and they may also be a valuable strength diagnosis tool for golfers. It should be noted, however, that medicine ball training should be conducted in addition to resistance training. A previous study with baseball players noted no change in running speed or throwing speed in baseball players participating in only medicine ball training (36). These results may be valuable in guiding strength and conditioning coaches and players in designing golf-specific training programs.

Previous work has not been done examining the effects of specific resistance training elements on golf performance. Further study is required to determine an optimal training program for golfers. For instance, Kraemer and colleagues (1998) noted greater sports-specific performance gains in collegiate tennis players following a periodized program compared with a nonperiodized resistance training program (22). Additionally, many golfers only strength train in off-season months and completely stop resistance training during the competitive season, which may not be beneficial to performance due to detraining effects (3). Collegiate, professional, and amateur golf seasons are very long and split into 2 time blocks. Measuring effects of a year-round, including in-season, linear or nonlinear periodized training program would be valuable. For instance, such a longer-term resistance-training program may cause increased muscle hypertrophy that could influence golf swing mechanics.

It is an important finding that physical conditioning has some positive and no negative effects on golf performance. Strength, power, and flexibility training may have beneficial effects for golfers other than overt improvements in distance and accuracy. For instance, resistance training has positive effects on bone, connective tissue, and cardiovascular responses (7, 24). These changes will influence quality of life and possibly have an effect on golf score, longevity, or injury prevention (37, 40). Additionally, a greater range of specialty shots may be possible with greater strength levels. This possibility has not been scientifically investigated; however, Tiger Woods anecdotally claims he could not hit his low, controlled tee shot, or "stinger," before a prolonged strength-training regimen (50). Increased strength in hands, arms, shoulders, and trunk may have helped him control the torque of the club at the bottom of the swing to prevent the club from releasing, while still generating high clubhead speed, resulting in a low, controlled shot. Finally, there may be some intangible benefits related to improved fitness, such as increased confidence, concentration, and more optimal stress response (34).

PRACTICAL APPLICATIONS

Competitive, recreational, and especially collegiate golfers have limitations on practice time. It is valuable to know the effects of different training methods to effectively allocate practice time. These results indicate that 11 weeks of physical conditioning increased clubhead speed without a negative effect on consistency or putting distance control in elite men and women golfers. Clubhead speed in elite men and women golfers increased to a lesser degree than in previously reported studies with less skilled golfers. This highlights the importance of creating golf and individual specific conditioning programs. Strength and power appear to be important factors in swinging the golf club fast, and skilled men and women golfers should engage in weight training, stretching, and rotational power training to improve golf performance.

REFERENCES

1. ANDERSON, T., AND J.T. KEARNEY. Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Res. Q. Exerc. Sport* 53:1–7. 1982.
2. BABINEAU, J.E. Golfweek collegiate golf rankings, 2001. Available at: www.golfweek.com/sagarin. Accessed June 23, 2001.
3. BAECHLE, T.R., AND R.W. EARLE. *Essentials of Strength Training and Conditioning.* Champaign, IL: Human Kinetics, 2000.
4. BURKE, R.E. The control of muscle force: Motor unit recruitment and firing patterns. In: *Human Muscle Power.* N.L. Jones, M. McCartney, and A.J. McComas, eds. Champaign, IL: Human Kinetics, 1986. pp. 97–106.
5. CHEETHAM, P.J., P.E. MARTIN, R.E. MOTTRAM, AND B.F. ST.-LAURENT. The importance of stretching the "x-factor" in the downswing of golf: The "x-factor stretch." In: *Optimising Performance in Golf*. P.R. Thomas, ed. Brisbane, Australia: Australian Academic Press Pty. Ltd., 2001. pp. 192–199.
6. COCHRAN, A., J. STOBBS, D. NOBLE, C.B. DAISH, AND W.F. FLOUD. *Search for the perfect swing: An account of the Golf Society of Great Britain Scientific Study.* Philadelphia, PA: Lippincott Co., 1968.
7. CONROY, B.P., W.J. KRAEMER, C.M. MARESH, S.J. FLECK, M.H. STONE, A.C. FRY, P.D. MILLER, AND G.P. DALSKY. Bone mineral density in elite junior Olympic weightlifters. *Med. Sci. Sports Exerc.* 25:1103–1109. 1993.
8. DILLMAN, C.J., AND G.W. LANGE. How has biomechanics contributed to the understanding of the golf swing? In: *Science and Golf II: Proceedings of the 1994 World Scientific Congress of Golf.* A.J. Cochran, and M.R. Farrally, eds. London: E. & F.N. Spon, 1994. pp. 3–13.
9. ENGLEHARDT, G.M. Differences in shot-making skills among high and low money winners on the PGA tour. *Percept. Mot. Skills* 84:1314. 1997.
10. FLETCHER, I.M., AND M. HARTWELL. Effect of an 8-week combined weights and plyometrics training program on golf drive performance. *J. Strength Cond. Res.* 18:59–62. 2004.
11. GWYN, R.G., AND C.E. PATCH. Comparing two putting styles for putting accuracy. *Percept. Mot. Skills* 76:387–390. 1993.
12. HÄKKINEN, K., AND P. KOMI. The effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. *Scand. J. Sports Sci.* 7:65–76. 1985.
13. HÄKKINEN, K., AND P.V. KOMI. Changes in electrical and mechanical behavior of leg extensor muscles during heavy resistance strength training (Les modifications des comportements electrique et mecanique des muscles extenseurs de la jambe au cours d'un entrainement de musculation a haute resistance). *Scand. J. Sports Sci. Finlande* 7:55–64. 1985.
14. HALE, T., AND G.T. HALE. Lies, damned lies and statistics in golf. In: *Science in Golf, Proceedings of the First World Scientific Congress of Golf.* A.J. Cochran, ed. New York: E. & F.N. Spon, 1990. pp. 159–164.
15. HETU, F.E., C.A. CHRISTIE, AND A.D. FAIGENBAUM. Effects of conditioning on physical fitness and club head speed in mature golfers. 1998.
16. HOPKINS, W.G., J.A. HAWLEY, AND L.M. BURKE. Design and analysis of research on sport performance enhancement. *Med. Sci. Sports Exerc.* 31:472–485. 1999.
17. JOBE, F.W., L.A. YOCUM, R.E. MOTTRAM, AND M.M. PINK. *Exercise Guide to Better Golf.* Inglewood, CA: Champion Press, 1994.
18. JONES, D. The effects of proprioceptive neuromuscular facilitation flexibility training on the clubhead speed of recreational golfers. *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf.* A.J. Cochran, ed. St. Andrews, Scotland: Human Kinetics, 1998.
19. JORGENSEN, T. On the dynamics of the swing of a golf club. *Am. J. Phys.* 38:644–651. 1970.
20. KANEKO, M., T. FUCHIMOTO, K. TOJI, AND K. SUEI. Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scand. J. Sports Sci.* 5:50–55. 1983.
21. KRAEMER, W.J., P.A. PIORKOWSKI, J.A. BUSH, A.L. GOMEZ, C.C. LOEBEL, J.S. VOLEK, R.U. NEWTON, S.A. MAZZETTI, S.W. ETWEILER, M. PUTUKIAN, AND W.J. SEBASTIANELLI. The effects of NCAA Division I intercollegiate competitive tennis match play on recovery of physical performance in women. *J. Strength Cond. Res.* 14:265–272. 2000.
22. KRAEMER, W.J., N. RATAMESS, A.C. FRY, T. TRIPLETT-MCBRIDE, L.P. KOZIRIS, J.A. BAUER, J.M. LYNCH, AND S.J. FLECK. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am. J. Sports Med.* 28:626–633. 2000.
23. KRAEMER, W.J., N.T. TRIPLETT, A.C. FRY, L.P. KOZIRIS, J.E. BAUER, J.M. LYNCH, T. MCCONNELL, R.U. NEWTON, S.E. GORDON, R.C. NELSON, AND H.G. KKNUTTGEN. An in-depth sports medicine profile of women college tennis players. *J. Sport Rehabil.* 4:79–98. 1995.
24. KRAEMER, W.J., J.S. VOLEK, K.L. CLARK, S.E. GORDON, T. INCLEDON, S.M. PUHL, N.T. TRIPLETT-MCBRIDE, J.M. MCBRIDE, M. PUTUKIAN, AND W.J. SEBASTIANELLI. Physiological adaptations to a weight-loss dietary regimen and exercise programs in women. *J. Appl. Physiol.* 83:270–279. 1997.
25. LANFORD, E.E. Effect of strength training on distance and accuracy in golf. Unpublished dissertation, Brigham Young University, Provo, UT, 1976.
26. LAUBACH, L.L. Comparative muscular strength of men and women: A review of the literature. *Aviat. Space Environ. Med.* 47:534–542. 1976.
27. LAUBER, D., J.L. MAYHEW, W. KEMMLER, AND J. WEINECK. Repetitions-to-fatigue to predict one repetition maximum bench press, squat, and deadlift in elite European powerlifters [Abstract]. *J. Strength Cond. Res.* 14:366. 2000.
28. LENNON, H.M. Physiological profiling and physical conditioning for elite golfers. *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf.* A.J. Cochran, ed. St. Andrews, Scotland: Human Kinetics, 1998. pp. 58–64.
29. LUND, R.J. *The Effects of a Torso Strengthening and Rotational Power Program vs Strength Training on Angular Hip, Angular Shoulder and Linear Bat Head Velocity in Male College Baseball Players.* Eugene, OR: Eastern Washington University, 1997.
30. MAZZETTI, S.A., W.J. KRAEMER, J.S. VOLEK, N.D. DUNCAN, N.A. RATAMESS, A.L. GOMEZ, R.U. NEWTON, K. HÄKKINEN, AND S.J. FLECK. The influence of direct supervision of resistance training on strength performance. *Med. Sci. Sports Exerc.* 32:1175–1184. 2000.
31. MCBRIDE, D.K. Provision of enabling technology in professional sports. *Percept. Mot. Skills* 90:1219–1231. 2000.

32. MCEVOY, K.P., AND R.U. NEWTON. Baseball throwing speed and base running speed: The effects of ballistic resistance training. *J. Strength Cond. Res.* 12:216–221. 1998.
33. MILBURN, P.D. Summation of segmental velocities in the golf swing. *Med. Sci. Sports Exerc.* 14:60–64. 1982.
34. MOYA-ALBIOL, L., A. SALVADOR, R. COSTA, S. MARTINEZ-SANCHIS, E. GONZALEZ-BONO, J. RICARTE, AND M. ARNEDO. Psychophysiological responses to the Stroop Task after a maximal cycle ergometry in elite sportsmen and physically active subjects. *Int. J. Psychophysiol.* 40:47–59. 2001.
35. NATIONAL SPORTING GOODS A. Exercise walking remains America's favorite participant sport, according to NSGA study. *NSGA News* 14:4. 2001.
36. NEWTON, R.U., AND K.P. MCEVOY. Baseball throwing velocity: A comparison of medicine ball training and weight training. *J. Strength Cond. Res.* 8:198–203. 1994.
37. PARCHMAN, L. L. *Cinematographical and Mechanical Analysis of the Golf Swing of Female Golfers.* Ann Arbor: University Microfilms, 1, 1970.
38. PELZ, D. *Dave Pelz's Putting Bible.* New York: Doubleday, 2000.
39. PINK, M., J. PERRY, AND F.W. JOBE. Electromyographic analysis of the trunk in golfers. *Am. J. Sports Med.* 21:385–388. 1993.
40. PINK, M.M., F.W. JOBE, L.A. YOCUM, AND R. MOTTRAM. Preventative exercises in golf: Arm, leg, and back. *Clin. Sports Med.* 15:147–162. 1996.
41. RICCIO, L.J. Statistical analysis of the average golfer. In: *Science in Golf, Proceedings of the First World Scientific Congress of Golf.* A.J. Cochran, ed. New York: E. & F.N. Spon, 1990. pp. 153–158.
42. ROBINSON, R.L. A study of the correlation between swing characteristics and club head velocity. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* A.J. Cochran, and M.R. Farrally, eds. London: E. & F.N. Spon, 1994. pp. 84–91.
43. SALE, D.G. Neural adaptation to resistance training. *Med. Sci. Sports Exerc.* 20:S135–145. 1988.
44. STONE, M.H., S.S. PLISK, M.E. STONE, B.K. SCHILLING, H.S. O'BRYANT, AND K.C. PIERCE. Athletic performance development: Volume load—1 set vs. multiple sets, training velocity and training variation. *Strength Cond.* 20:22–31. 1998.
45. STROHMEYER, D.D. Effect of an exercise training program on grip strength and hitting distance and the relationship of grip strength and arm length to hitting distance in golf with a five iron. Unpublished Master's thesis, University of Kansas, Lawrence, KS, 1973.
46. THOMAS, J.R., AND J.K. NELSON. *Research Methods in Physical Activity.* Champaign, IL: Human Kinetics, 1996.
47. VAN TIJN, S., AND C.W. GRIFFING. Search of the perfect golf ball. Extraordinary evolution of the dimpled orb Maximum test. Why how the USGA is setting overall distance standards for golf balls and clubs. *Financial Post Magazine* 20:10–12. 1977.
48. WALTON, J.S. *Close-Range Cine-Photogrammetry: A Generalized Technique for Quantifying Gross Human Motion.* University Park, PA: Pennsylvania State University, 1981.
49. WATKINS, R.G., G.S. UPPAL, J. PERRY, M. PINK, AND J.M. DINSAY. Dynamic electromyographic analysis of trunk musculature in professional golfers. *Am. J. Sports Med.* 24:535–538. 1996.
50. WEATHERS, E. Tiger's supersonic stinger. *Golf Digest* 51(Apr): 84–88. 2000.
51. WENZEL, D. Weight training and its effect on the golf drive. Unpublished Master's thesis, University of North Dakota, Grand Forks, ND, 1967.
52. WESTCOTT, W.L., F. DOLAN, AND T. CAVICCHI. Golf and strength training are compatible activities. *Strength Cond.* 18: 54–56. 1996.
53. WESTCOTT, W.L., AND J.R. PARZIALE. Golf power: Strength training takes its place alongside flexibility training for improving both power and speed in the golfer's swing. *Fitness Manage.* 13:39–41. 1997.
54. WHITTAKER, A.R. A study of the dynamics of the golf club. *Sports Eng.* 1:115–124. 1998.
55. WILSON, G., R. NEWTON, A. MURPHY, AND B. HUMPHRIES. The optimal training load for the development of dynamic athletic performance. *Med. Sci. Sports Exerc.* 25:1279–1286. 1993.
56. WIREN, G. Laws, principles and preference–A teaching model. In: *Science and Golf, Proceedings of the First World Scientific Congress of Golf* (1st ed.). A.J. Cochran, ed. London: E. & F.N. Spon, 1990. pp. 3–13.
57. ZATSIORSKY, V.M. *Science and Practice of Strength Training.* Champaign, IL: Human Kinetics, 1995.
58. ZHANG, J. The correlation among three hand strength measurement methods: Hand dynamometer. Master's thesis, Ball State University, Muncie, IN, 1996.

Acknowledgments

We would like to thank the following people and organizations for their support of this investigation: (a) Ball State University 2000–2001 Men's and Women's golf team and head coaches (Mike Fleck and Shelley Saunders) for their hard work and dedication in the completion of this experiment, (b) Doug Bishop for the use of his indoor golf facility (MD's), and (c) Focaltron for the donation of the GolfAchiever.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, the Department of Defense, or the U.S. Government.

Address Correspondence to Brandon K. Doan, Brandon.Doan@usafa.af.mil.