REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10.Jun.02	DISSERTATION

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
THE EFFECTS OF RESISTANCE TRAINING ON GOLF PERFORMANCE AND PHYSIOLOGICAL STRESS RESPONSE DURING COMPETITION IN INTERCOLLEGIATE GOLFERS	
6. AUTHOR(S)	
CAPT DOAN BRANDON K	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
BALL STATE UNIVERSITY	CI02-76

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
THE DEPARTMENT OF THE AIR FORCE AFIT/CIA, BLDG 125 2950 P STREET WPAFB OH 45433	

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Unlimited distribution In Accordance With AFI 35-205/AFIT Sup 1	

13. ABSTRACT *(Maximum 200 words)*

20020702 030

14. SUBJECT TERMS	15. NUMBER OF PAGES
	186
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

EFFECTS OF RESISTANCE TRAINING ON GOLF PERFORMANCE AND PHYSIOLOGICAL STRESS RESPONSE DURING COMPETITION IN INTERCOLLEGIATE GOLFERS

A DISSERTATION SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE

DOCTOR OF PHILOSOPHY

BY

BRANDON K. DOAN

APPROVED BY:

Committee Chairperson	Date 4/12/2002
Committee Member	Date 4/12/2002
Committee Member	Date 4/12/2002
Committee Member	Date 4/12/2002
Committee Member	Date April 12, 2002

BALL STATE UNIVERSITY
MUNCIE, IN
MAY, 2002

THE EFFECTS OF RESISTANCE TRAINING ON GOLF PERFORMANCE AND PHYSIOLOGICAL STRESS RESPONSE DURING COMPETITION IN INTERCOLLEGIATE GOLFERS

A DISSERTATION SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

DOCTOR OF PHILOSOPHY

BY

BRANDON K. DOAN

ADVISOR: DR. ROBERT NEWTON

BALL STATE UNIVERSITY

MUNCIE, IN

MAY, 2002

DECLARATION

The work presented in this Dissertation is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Brandon K. Doan

ABSTRACT

Two investigations were conducted with collegiate golfers for separate, but related purposes. 1) To investigate the effects of a physical conditioning program (strength, power and flexibility training) on clubhead speed, consistency, and putting distance control. 2) To investigate the effects of 36 continuous holes of competitive golf on testosterone and cortisol response and their relation to performance.

Study #1: Subjects were ten men and six women NCAA Division I golfers. Supervised strength, power, and flexibility training was performed 3 times per week for 11 weeks. Golf ball launch conditions, putting distance control, strength, power, and flexibility tests were conducted before and after training. Significant ($p < 0.05$) increases were noted for all strength, power, and flexibility tests. Clubhead speed increased significantly (1.6%) from pre to post training, equating to a 4.9-meter increase in driving distance. No significant differences were observed for clubface-angle or launch-angle deviation. Putting distance performance significantly improved for the men-only group (29.6%). Significant ($p < .05$) correlations resulted between clubhead speed and rotational power ($r = 0.86$) for the men-only group. Qualitative video analysis did not show any consistent trends in swing mechanics alterations. Eleven weeks of physical conditioning increased clubhead speed without a negative effect on consistency or putting distance control in intercollegiate men and women golfers. ***Study #2:*** Subjects were eight NCAA Division I men golfers. Saliva samples were taken 45 minutes prior to the round and after each hole during a 36-hole competition. Time matched baseline samples were collected. Six and 36-hole area under the curve (AUC) values were calculated for endocrine measures. Salivary cortisol increased by 111% ($p < 0.05$) during competition compared to baseline. Testosterone-to-cortisol ratio was significantly lower (45%) throughout the competition compared to baseline. Significant ($p < 0.05$) correlations resulted between: 36-hole AUC testosterone-to-cortisol ratio difference and 36-hole score ($r = 0.82$), CSAI-2 somatic anxiety and pre-round cortisol ($r = 0.81$), testosterone ($r = -0.80$), and testosterone-to-cortisol ratio ($r = -0.72$). These results indicate a significant hormonal strain during 10 hours of competitive golf, low T/C ratio relation with low golf scores, and CSAI-2 relation with endocrine measures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND NOMENCLATURE

AUC – Area Under the Curve

CRH – Corticotropin-Releasing Hormone

CSAI-2 – Competitive State Anxiety Inventory 2

EMG - Electromyography

FSH – Follicle-Stimulating Hormone

GAS - General Adaptation Syndrome

*GnR*H – Gonadotropin-Releasing Hormone

HPAA - Hypothalamic-Pituitary-Adrenal Axis

LH - Luteinizing Hormone

NCAA – National Collegiate Athletic Association

RM – Repetition Maximum

SHBG – Sex-Hormone-Binding Globulin

T/C Ratio – Testosterone-to-Cortisol Ratio

Chapter 1

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 10^{th} in total participation when compared to all other sports and recreational activities. The total number of golfers in the United States has increased by 10% since 1995 [133].

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, gender, and 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 where 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 competitions 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, improved physiological capabilities (strength, power, flexibility, endurance, etc), improved and individually matched equipment, and improved competition management skills (sports psychology) (Figure 1.1). Scientists, 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 [2, 4, 10, 24, 29, 34, 36, 48, 69, 75, 79, 81, 86, 87, 102, 108, 127-129, 135-137, 141, 142, 154, 157, 158, 163, 165, 185, 200]. Investigators and 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 [19, 25, 30, 46, 54, 78, 116, 151, 179, 195]. Less research has been done in conditioning or training human physiological systems for optimal golf performance, although this may be an important area for investigation because physical capabilities may affect golf performance directly by increasing maximum distance and accuracy. Additionally, improved physiological function through training may improve technique as increased strength and flexibility allow more optimal mechanics, as well as longer, more effective practice sessions. Lastly, increased physiological function may reduce fatigue in competition and allow better response to the stress of competition [130]. Obviously, golfers are individuals and each one will have a different body type, responses to stress, coping strategies, and different strengths and weaknesses. It is the task of the coach and golfer to determine the most optimal training and practice program for the individual.

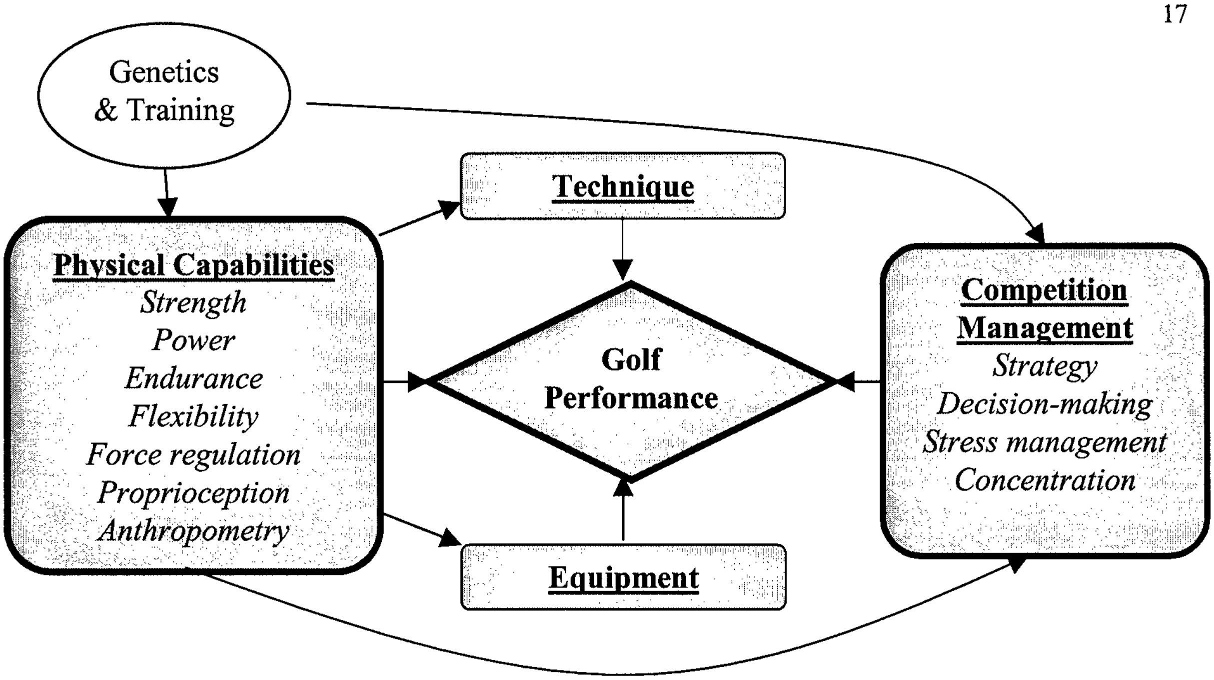


Figure 1.1: Golf Performance Factors

Golf is a bilateral sport and studies using EMG have shown significant activity in a majority of the muscles of the body during the golf swing [13, 70, 71, 80, 131, 148, 149, 188]. Despite these findings, until recently, a 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. The PGA Tour has a fitness trailer filled with physical therapists and strength and conditioning specialists at each event, while many of the top players are working with personal strength and conditioning trainers. However, there is still limited scientific research analyzing the effects of strength, power, and flexibility training on golf performance, particularly with elite golfers.

Some investigators have studied the effects of strength, power, and flexibility training on golf performance [64, 74, 103, 106, 168, 190, 193, 194]. Strength increases were reported between 5% and 56%, while flexibility improved 7 to 39%. Subjects involved in these investigations were mostly recreational amateur male golfers and increased clubhead speed by 3 to 7% or driving distance by 10 to 15 yards, with no reported negative accuracy effects. However, these findings may not apply to more skilled men and women golfers.

Measurable performance gains and adaptations require more intense training in highly skilled versus novice athletes [56, 57, 167] and estimated gains in novice performance may not apply to elite athletes [66]. Additionally, Jorgenson (1970), using a mathematical model determined there are two important components contributing to clubhead speed: the amount of torque supplied by the golfer and the skill with which the golfer manages the torque [75]. Therefore, more skilled men and women golfers may respond differently to physical conditioning, in terms of golf performance, than recreational golfers.

The effect of resistance training on elite or competitive-level women golfers has not been investigated. Women's professional golf is much newer then men's and strength training has been traditionally less acceptable among women compared to men. Differences between men and women in upper body strength and body composition suggest possibly different effects on performance [104, 197]. Driving distances for women are significantly shorter than for men and any improvement in driving distance may play a more important role in overall golf performance.

The effects of resistance training on distance control in putting have also not been previously studied. Increased strength of postural muscles may allow a more stable platform for execution of the putting stroke. Improvements in motor unit recruitment and firing patterns have been noted with resistance training, which may improve regulation of force [16]. Regulation of force is an important element in distance control, which is essential in any less-than-full length golf shot. Overall golf performance would be enhanced, especially since an average of 40% of all golf shots in an 18-hole round are putts [53].

Finally, the effects of resistance training on consistency have not been studied. Studies have shown that resistance training will improve muscular strength and local muscular endurance [5], which may have an impact on golf swing consistency during an 8-hour, 36-hole round of competitive golf where 130 or more golf shots are executed. Consistency is an important factor in a target-oriented individual sport like golf where the player does not have to react to a moving ball or competitor. Knowing where the golf ball will go on a consistent basis is important. Stronger, more fatigue-resistant muscles may reduce undesirable changes in the swing during extended practice sessions and competition.

In addition to physiological and biomechanical factors, psychological factors are important to sport performance. Orlick and Partington (1988) reported mental readiness as having the only statistically significant link to final sport performance, while technical and physical readiness factors were not related to final ranking. Golf is not traditionally thought of as a physically stressful sport [111]. However, the psychological stress of competitive golf may elicit a physiological stress response large enough to have an impact on acute and long-term performance.

Limited research has been performed with competitive golf and stress response. Higher cortisol in competitive versus practice golf has been noted, but performance based on cortisol levels could not be predicted [126]. A significant stress response based on neurotrasmitter elevations during competition versus practice and different patterns of response for differing skill levels of collegiate golfers has also been reported [98]. Cortisol and testosterone have been studied in relation to other stressors and sports.

Serum cortisol concentration may be elevated during and after athletic performance due to anticipation of or in response to psychological stressors [6, 84, 115] or physical exertion of 70% or higher of $\dot{V}O_2max$ [35, 114]. Although not typically associated with stress response, rises in testosterone have been associated with increased physical stress, such as short-term maximal exercise [88-90, 93], and psychological stress [52, 162]. Higher testosterone has also been associated with mood states such as competitiveness, drive, persistence, and contribution to winning [32, 63].

Testosterone-to-cortisol (T/C) ratio is a good indicator of anabolic/catabolic status and is an indicator of overtraining in aerobic endurance-type activities [1, 9]. T/C ratio decreases as exercise intensity and duration increase, as well as during intense training or competition periods [176]. In a recent review article, Clow and Hucklebridge (2001) suggested endurance overtraining and chronic psychological stress to have similar effects [23].

Several investigators have studied the effects of anxiety on sport performance. However, no single theory seems to explain the effects of anxiety on all types of sport performance. Two challenges exist in relating anxiety to sport performance: 1) accurate and reliable measurement of anxiety 2) accurate and reliable measurement of actual sport performance [153]. Most scientists investigating the relationship between anxiety and sports performance have used the Competitive State Anxiety Inventory-2 (CSAI-2) [113]. However, few studies have validated the CSAI-2 with physiological measures of anxiety [42, 113].

Men's NCAA Division I golf teams play 12 or more tournaments each season and tournaments are normally played over two days with 36 holes played on the first day and 18 holes on the second day. The playing of 36 holes in one day was implemented to reduce number of days of the competition while maximizing the number of competitive rounds. As golf has become more popular, golf courses are less willing to allow collegiate golfers to take course time away from paying customers. Additionally, universities, coaches and players strive to minimize time away from class. Other amateur golf tournaments, such as the U.S. Amateur Championship require playing of 36 holes for several consecutive days.

An 18-hole competitive round lasts from 4 to 6 hours, while a 36-hole competitive round might last 8 to 12 hours. When metabolic demands are combined with the psychological stress of competition there may be a significant endocrine response to competitive golf, which may have an impact on performance, recovery, and long-term health.

There are two separate, but related purposes for this investigation. 1) To investigate the effects of a physical conditioning program (strength, power, and flexibility training) on club head speed, consistency, and putting distance control in elite college-level men and women golfers. 2) To study the effects of 36 continuous holes of competitive golf on testosterone and cortisol secretion and their relation to performance in elite male competitive collegiate golfers. A secondary purpose was to relate pre-competition CSAI-2 measures of perceived anxiety to cortisol and testosterone response.

Significance of the Study

Any advancement or finding in the science of golf would have an impact on a very large and diverse segment of the population. Physical conditioning improves clubhead speed and driving distance in recreational amateur golfers [64, 74, 103, 106, 168, 190, 193, 194] and may improve driving distance in professional or elite men and women golfers, which has been positively correlated with score in average golfers ($r = 0.64$) [156] and elite golfers ($r = 0.49$ to $r = 0.84$) [58]. In a statistical comparison of performance variables for the players on the 1995 PGA Tour, only driving distance and total driving (distance and accuracy) measures were significantly different ($p < .05$) between the top and bottom 10 money winners [40]. Physical conditioning may also improve performance in the short game [190] and reduce fatigue related declines in performance. Cochran and colleagues (1968) studied the performance of a group of professional golfers playing in a professional tournament [24]. They concluded that a 20-yard 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, while doubling the accuracy of putting would save 4.2 strokes per round. A single stroke difference during a 72-hole tournament on the PGA tour is worth about $8, 000 [122].

Information as to the effects of strength, power, and flexibility training on golf performance in elite players would be of great importance to coaches, players, and strength and conditioning coaches. Competitive, recreational, and especially collegiate golfers have limitations on practice time. It is valuable to know the effects of different training methods in order to effectively allocate practice time.

Physiological stress response may be correlated to previous golf performance and have an effect on subsequent golf performance. Additionally, measuring physiological stress response during 36-holes of carrying a golf bag in competition may provide valuable information for golfers, coaches, and clinicians. Noninvasive measures of anxiety are a valuable tool in research and their validation with biological measures and competition in real-life events and correlation to performance in competition is important. Lastly, findings from this investigation may also be applicable to other forms of physical, occupational, or mental stress. Golf requires relatively low physical exertion; therefore, any changes in testosterone or cortisol secretion pattern or magnitude during golf performance are primarily a result of psychological stress. There are very few competitive or stressful environments that are feasible to regular saliva collection at frequent time intervals over almost an entire wakeful day (9+ hours).

Hypotheses

The following hypotheses were examined in this investigation:

Study #1: *The Effects of Resistance Training on Golf Performance in Competitive Intercollegiate Men and Women Golfers*

Following strength, power and flexibility training:

1. Strength, trunk power, and trunk flexibility will increase.
2. Swing mechanics will not change.
3. Clubhead speed will increase.
4. Consistency will not change.
5. Putting distance control will improve.

Study #2: *Physiological Stress Response During Competitive Golf*

1. Salivary cortisol will be higher in golf tournament competition than a baseline condition.
2. Salivary testosterone will not change in golf tournament competition compared to a baseline condition.
3. T/C ratio will be lower in golf tournament competition than a baseline condition.
4. Perceived fatigue will be greater during competition than baseline.
5. Salivary cortisol will be negatively correlated to performance.
6. Salivary T/C ratio will be positively correlated to performance.
7. Pre-competition salivary cortisol will be positively correlated to pre-competition somatic anxiety as measured by the CSAI-2.
8. Pre-round salivary testosterone will be elevated in competition compared to baseline.
9. Pre-round salivary cortisol will be elevated in competition compared to baseline.

Chapter 2

REVIEW OF LITERATURE

Introduction

This literature review will explore a number of areas pertaining to the topic. Previous research assessing the effects of resistance training on golf performance will begin the review. A biomechanical movement analysis of the golf swing will be discussed in order to design and validate the training program. Research on specific golf swing fundamentals important for maximization of clubhead speed will be reviewed in order to understand possible changes in swing mechanics (technique) due to physical conditioning.

The second half of the literature review will focus on biochemical and physiological responses to stressful episodes. The specific effects of stress on body systems will be discussed, as well as testosterone and cortisol responses before and after sports competition and their association with performance. The reliability and validity of using salivary cortisol and testosterone measures will be reviewed. Additionally, there will be a brief discussion of competitive anxiety in sport. The literature review will conclude with a summary of the research and directions for further study.

Golf and Physical Conditioning

There is limited scientific research investigating the effects of strength, power, and flexibility training on golf performance. The majority of previous studies have investigated male recreational golfers and all investigations have reported a positive effect of resistance and flexibility training on golf performance. See Table 2.7 for a summary of investigations.

In an unpublished masters thesis, Richard Wenzel investigated the effects of 8 weeks of resistance training on 10 male golfers and reported significant increases ($p < 0.01$) in driving distance (5.6%) and chipping accuracy (50%), with no change in driving accuracy [190]. Eight of the subjects were members of the university golf team and two were graduate students whose skill level was not described. The best five of ten shots were used for statistical analysis for each test. For the conditioning program, two sets of 8 to 12 repetitions were performed twice per week using 13 isometric and isotonic exercises to strengthen the muscles of the wrists, forearms, shoulders, back, chest and legs. No rationale was given for including the isometric exercises, which may not be the most beneficial form of strength training for golf performance. Golf skills practice may have been a confounding variable in this investigation because the strength-training program was conducted between January and March, while the golf testing was not conducted until May and golf practice was not controlled. The pre-testing was done in January, presumably several months after the competitive golf season with no mention of any off-season practice. Physiological adaptations due to the strength-training program could not be evaluated because tests to evaluate strength changes were not performed.

In an unpublished dissertation, Gary Wiren investigated the importance of human factors in the golf drive for distance [200]. Wiren tested 51 male subjects with handicaps from 0 to 14 on driving distance, anthropometric, strength, flexibility and timing measures. Wiren compared the longest and shortest hitters and computed correlations and a regression analysis. He reported a positive relationship between all measures and driving distance with strength and timing being the most related to the drive for distance.

In another unpublished dissertation, Eric Lanford investigated the effects of a 10-week resistance training protocol on golf driving distance and accuracy [103]. The subject pool included 32 men with a handicap of 10 handicaps or less and 10 women of undescribed ability. Subjects performed 2 sets of 6 repetitions of various basic free-weight resistance-training exercises 3 times per week. Significant ($p < 0.05$) increases in driving distance when comparing pre to post training values were reported for the total experimental group (6.9%, 11.82 yards) and the men-only experimental group (4.1%, 8.62 yards). A trend towards increased distance was reported in the female-only experimental group, however statistical significance was not achieved. No difference in driving distance was reported for the control group. No differences were noted between pre and post-training chipping accuracy scores between the experimental and control groups. Additionally, high correlations were reported between driving distance and right (0.95) and left (0.96) grip strength and bench press 1 RM (0.89).

In an unpublished masters thesis, Daniel Strohmeyer investigated the effects of four weeks of grip strength training on golf performance [168]. Subjects included 20 men age 13 to 26, with golf handicaps between 4 and 18. The training program included grip strength-only exercises and was performed 3 times per week for 25 minutes each session. In the control group grip strength and 5-iron distance did not change. However, significant increases ($p < 0.05$) were reported for right grip strength (4.8%), left grip strength (10.5%), and 5-iron distance (5.9%) in the experimental group. 5-iron accuracy did not change for the experimental or control group. Additionally a significant correlation of .661 was reported for right grip strength and 5-iron distance.

A more recent study investigated the effects of eight weeks of physical training on golf in three separate groups of untrained recreational golfers: a group performing strength training only ($N = 31$, mean age = 52 years), a group performing flexibility training only ($N = 8$, mean age = 56 years), and a group combining strength and flexibility training ($N = 17$, mean age = 58 years) [194]. Investigators reported that 8 weeks of Nautilus strength training and stretching exercises significantly ($p < 0.05$) increased clubhead speed by 6% (5 mph), while the strength training only group increased clubhead speed by 3% (3 mph). A 56% increase in 10 RM leg extension was noted with the strength and flexibility group, while a 58% increase was noted for the strength-only group. Significant increases in shoulder abduction (7.1%), hip flexion (21.5%), and hip extension (44.2%) flexibility were reported for the strength and flexibility group, while the strength group did not increase flexibility measures. The flexibility-only study was reported as a preliminary study with only 8 subjects with chronic low-back pain. Mean flexibility and clubhead speed for the flexibility-only group increased by 18.7% and 6.4% (5 mph), respectively, although statistical significance was not reported for this group.

Hetu and colleagues (1998) investigated the effects of 8 weeks of flexibility and resistance training on golf performance in an older population [64]. Subjects included 12 men and 5 women (age 39 to 63). Investigators reported a 6% increase ($p < .05$) in clubhead speed following the training. Significant increases in strength measures were noted for grip strength (6.2%), 1 RM leg extension (18.1%), 1 RM chest press (14.2%), sit and reach (38.8%), and total body rotation flexibility (37.3%).

Lennon (1999) reported interesting results from two investigations. First, he reported an increase in distance and no accuracy change on a 5-iron skill test in 14 elite male junior players (mean age = 16) following 8 weeks of golf specific training. Further details of the training program were not provided. Significant improvements were noted in grip strength, leg strength, and aerobic endurance. Actual values were not reported. Sit and reach flexibility increased significantly by 38.8% and shoulder rotation increased by 17.7%. No changes in 5-iron skill test, strength or flexibility measures were reported for a control group.

Lennon (1999)'s second investigation involved 26 members of the Irish Boys Golf Team and 2 European Tour players. The training program consisted of 1 year aerobic, strength, flexibility, proprioceptor training and golf drills based on weaknesses identified in individual profiling. Investigators noted significant increases in dynamic trunk rotation measured by 3-dimensional motion analysis of golf swings. No other performance measures were reported, however, subject's tournament performance and money winnings for that season were reported as their highest ever. It is difficult to attribute performance changes in this investigation directly to the training program. It seems many other factors could cause performance changes over a year's time.

Jones (1998) investigated the effects of a Proprioceptive Neuromuscular Facilitation (PNF) stretching program on clubhead speed [74]. Subjects were 16 men with an average age of 58 years old and golf handicaps ranging between 8 and 34. The eight-week PNF stretching program focused on the shoulders, hips and spine. Sessions were conducted 3 times per week for 45 minutes. Clubhead speed increased significantly (7.2%, 5.6 mph) from pre to post PNF training. Increases in hip flexion (7.1%), hip extension (35.3%), shoulder abduction (8.6%), shoulder external rotation (8.9%), and trunk rotation left (23.5%) and right (25.1%) were also noted. The increases in ranges of motion may allow more optimal swing mechanics or more time to generate clubhead speed by increasing the functional length of the back swing.

It is clear from the review of directly related previous research that strength, power, and flexibility training have a positive influence on golf performance in recreational male golfers. The effects of physical conditioning on more skilled men and women golfers, however, is unclear and requires further investigation. Additionally, most of the subjects that participated in previous investigations did not have any resistance training experience. Importantly, previous conditioning programs consisted primarily of basic resistance training exercises in the 8 to 12 repetition range. No previous investigations included power or high velocity exercises that more closely match the movement pattern of the golf swing. Also, most exercise programs were short in duration (4 to 12 weeks).

Table 2.1: Summary of Previous Research –The Effects of Physical Conditioning on Golf Performance

Investigation	Date	Subjects	Training program	Strength Increase	Flexibility Increase	Golf Result
Wenzel	1967	10 male golfers	8 weeks resistance training, 2 sets of 8-12 reps 2X per week	Not reported	NA	↑ D (5.6%) ↑ Chip A (50%)
Strohmeyer	1976	20 men age 13-26, HC 4 to 18	4 weeks of GS only training (3Xweek for 25 min.)	↑R GS (4.8%) ↑L GS (10.5%) 10.5%	NA	↑ D (5.9%), ↔ A D © R GS (.66) D © L GS (.90)
Lanford	1978	32 men (≤10 HC), 10 women (no HC)	10 weeks resistance training only 2 sets X 6 Reps (3X week)	↑BP (M20%, W48%), ↑GS (M15%, W39%)	NA	↑ D in T (6.9%) ↔ D in W, ↔ A D © R GS. (.95) D © L GS (.96) D © BP (.89)
Westcott & Parziale	1995	17 recreational golfers	8 weeks Nautilus and stretching		NA	↑ CHS (6%)
Westcott et al.	1996	17 serious golfers (13 M, 4 W)	Strengthening/stretching (40 min/ 10 min) 8 weeks, 1 set, 8-12 reps	↑10 RM leg extension (56%)	↑ SA (12%) ↑ HF (16.%) ↑ HE (8%)	↑CHS (6%)
Hetu & Christie	1998	12 male, 5 female age 39-63	8 weeks strength, flexibility and plyometrics	↑GS (6.2%) ↑ leg extension (18.1%) ↑ chest press (14.2%)	↑SR (39%) ↑TR (37%)	↑CHS (6%)
Lennon	1999a	14 teenagers (mean age = 16)	8 weeks of golf-specific physical conditioning 4X per week	↑GS, leg strength, and aerobic endurance	↑SR (39%) TR (18%)	↑ D (5.9%) ↔ A
Lennon	1999b	26 Irish boys team members, 2 Tour Players	1 year Aerobic, strength, flexibility, proprioceptor, golf drills	Not reported	↑ Dynamic ↑TR	↑Tournament performance and money winnings
Jones	1999	16 men average age of 58, 8-34 HC	8 weeks, 3Xweek for 45 mins, shoulders hips and spine PNF stretching	↑Hip flexion/extension, shoulder abduct, external rotation, trunk rotation	NA	↑CHS (6%) (no ball)

HC = Handicap; **CHS** = clubhead speed: **D** = Distance; **A** = Accuracy; © = significant correlation between variables ($p < 0.05$):
↑ = Significant increase ($p < 0.05$); ↔ = no significant change; **W** = women only group, **M** = men only group, **BP** = Bench Press, **GS** = Grip Strength, **SA** = shoulder abduction, **HF** = hip flexion, **HE** = hip extension, **TR** = trunk rotation, **SR** = sit-and-reach, **R** = right, **L** = left

Golf Swing Movement Analysis

Basic Biomechanical Description of the Golf Swing

The full golf swing is a kinetic link system with a back swing or "wind up" and a synchronized downswing or uncoiling motion. The full swing is generally the same for the drive and iron shots. The back swing, or the counter-movement, stores elastic energy and positions the body for the downswing. The hands and arms begin to take the club back in a plane perpendicular to the right shoulder, roughly defined by the angle of the club shaft at address. The golfer's weight begins to shift over a slightly flexed right leg as the shoulders begin to turn with the hips in trail. At the top of the back swing, the golfer is completely coiled with the wrists cocked and shoulders turned to about 90 degrees, while the hips have turned only about 65%–maximizing the stretch-reflex action, and the upper body has shifted laterally so that approximately 85% of the golfer's weight is over the right foot. All this occurs while the body maintains its initial knee bend and spine angle. However, slightly before the golfer reaches the top of the back swing, the hips have begun to shift back towards the target–initiating the downswing and storing more elastic energy.

Soon after the hips have begun their shift and turn back to the target, the torso begins to rotate. As the torso rotates, the hips begin to decelerate–transferring angular momentum to the torso (similar to snapping a whip). The arms now begin to swing down to the ball, as the hips and trunk decelerate, again transferring angular momentum. The arms decelerate and transfer all the stored up angular momentum to the club by uncocking the wrists and arriving at the ball with the arms and wrists fully extended. Momentum carries the golfer onto his left leg into the follow through position. Most of the major muscles in the body are used when performing an optimal golf swing.

Strength, Power, and Flexibility Definitions

Strength, power, and flexibility are often used differently in the description of human movement. To ensure clarity, I will define these terms for the purpose of this dissertation. Strength is defined as the maximal force a muscle or group of muscles can generate at a specified velocity during a concentric, eccentric, or isometric muscle contraction. Power is the rate of doing work or the product of force and velocity [85]. Flexibility is defined as the range of motion about a given body joint [8].

EMG Verification of Muscles Fired in the Golf Swing

Several electromyographic (EMG) analyses indicate the specific contributions of several muscle groups to the different phases of the golf swing. Jobe, Moynes and Antonelli (1986) investigated muscle activity in the shoulder area of professional men golfers during the golf swing using EMG and high-speed photography. Results of the study indicated that the following muscles are activated: the rotator cuff muscle group, anterior deltoid, latissimus dorsi, and pectoralis major. Specifically, the subscapularis was more active than any other muscle throughout the golf swing, especially during the acceleration phase when the right arm is internally rotating. The latissimus dorsi and pectoralis major were also activated bilaterally during the acceleration phase of the swing.

Additionally, the infraspinatus and supraspinatus are external rotators, abductors, and stabilizers throughout the swing [70, 148].

Pink and colleagues (1993) investigated the EMG activity of the trunk musculature during the golf swing. Their results revealed high constant activity of the trunk muscles used for stabilization and rotation in the golf swing. Erector spinae muscles were bilaterally active during the entire swing, but highest activity was recorded during the down and acceleration phases of the swing to maintain posture. Target and non-target side abdominal obliques were most active during the acceleration and early follow through phases of the swing, contributing to trunk rotation.

Centinela Hospital Medical Center conducted another EMG study of the hip and knee during the golf swing [13]. Results of the study revealed significant activity in non-target leg hip extensors, abductors and lead leg adductor magnus to initiate pelvic rotation during the down swing. Hamstrings of the target leg maintain a flexed knee and provide a stable base for pelvic rotation. The hamstrings muscle group, along with erector spinae, was also valuable in maintaining the trunk angle, or posture, during the swing. Additionally the gluteus medius and gluteus minimus (hip abductors) were active during the early acceleration phase of the swing. Gluteus maximus muscles were observed to be active during weight shift toward the target in the initiation of the acceleration and follow through phases of the swing [188].

Muscles of the arms and hands have not been studied using EMG. However, the hands are the only link the human has to the club, so one would suspect activity in these muscle groups to be high, particularly in the finger flexor group. The target-side tricep and bicep muscle groups contract isometrically during the back swing, downswing, and early follow through to keep the left arm extended. The non-target tricep will concentrically contract to extend the elbow during the downswing. Wrist flexor and extensor muscles will be contracted isometrically to stabilize the wrist joint, while radial and ulnar flexors will be active in controlling the cocking and uncocking of the wrists. Additionally, finger flexors will be activated to hold onto the grip of the club. Forearm supinators and pronators will also have some activity in controlling forearm rotation in late downswing and early follow through. Specific joint movements and muscles used during the golf swing are outlined in Tables 2.1 through 2.4.

For the purpose of this movement analysis, the golf swing will be divided into four stages: (see Figure 2.1)

1) Take away: from the static stance position to the top of the backswing

2) Forward Swing: from the top of the backswing until the club shaft is horizontal to the ground on the way down to the ball

3) Acceleration: from club-shaft horizontal to ball contact

4) Follow-through: from ball impact to the end of the motion

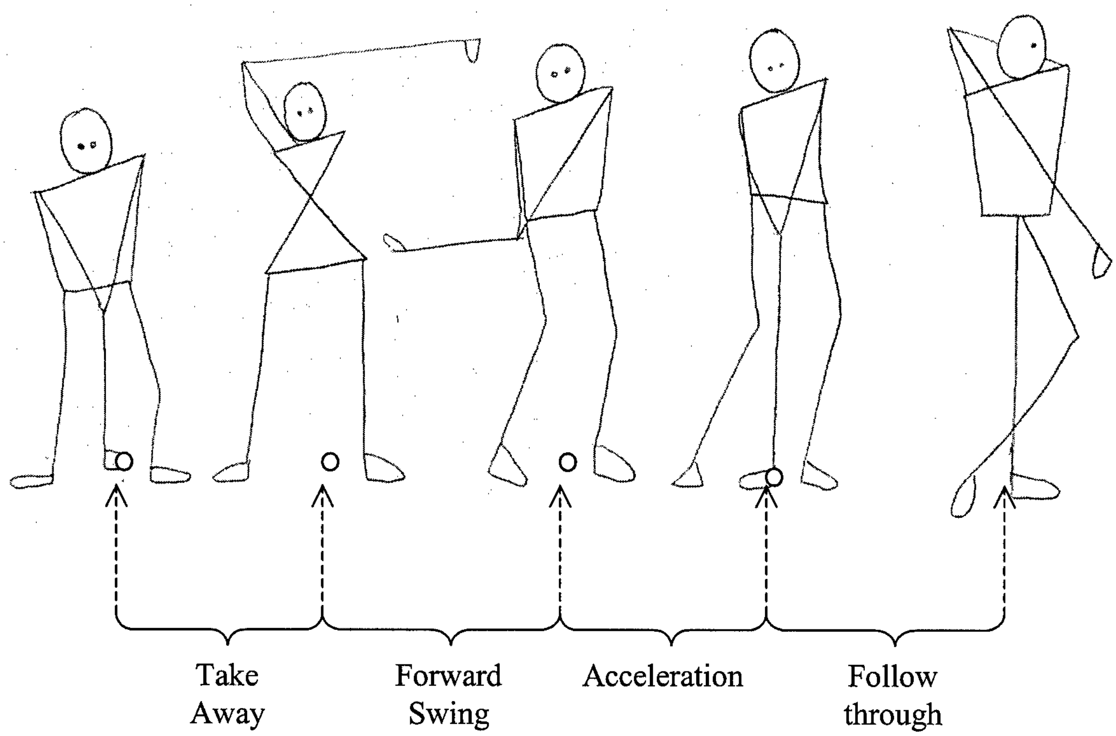


Figure 2.1: Golf Swing Phases

Table 2.2: Muscles Used in the Golf Swing (Backswing)

Joint	Action	Muscle	Side
*Hand	Grip Club (Finger Flexion)	Finger Flexors	Both
Wrist	Stabilize and cock wrist (Radial Flexion)	Flexor carpi radialis, Wrist flexors and extensors	Both
Radio-Ulnar	Pronation	Pronator teres, pronator quadratus, brachioradialis	Target
	Supination	Supinator, biceps brachii, brachioradialis	Non-Target
Elbow	Elbow flexion (raising of club)	Biceps Brachii, Brachialis	Non-Target
	Elbow extension	Triceps Brachii	Target
Shoulder	Internal rotation	Pectoralis major	Target
	Internal Rotation	Subscapularis	Target
	Stabilization and abduction	Supraspinatus	Non-Target
	Stabilization/external arm rotation	Infraspinatus	Non-Target
	Shoulder stabilization	Teres Minor	Non-Target
Trunk	Rotation and posture stabilization	Internal and External Obliques, Erector Spinae, and Rectus abdominis	Both
Hip	Lateral movement (abduction)	Hip Abductors (Gluteus minimus/medius/maximus, Tensor fascia lata)	Target
	Rotation	Lateral Rotator Group (gluteus maximus, piriformis, and gemelus superior)	Target
Knee	Maintain angle	Hamstrings, Quadriceps.	Both
	Extension	Quadriceps	Target

*Similar activation in all four phases of swing

Table 2.3: Muscles Used in the Golf Swing (Forward Swing)

Joint	Action	Muscle	Side
Wrist	Stabilization of wrist cock	Flexor and Extensor carpi ulnaris, wrist flexors and extensors	Both
Elbow	Extension	Triceps	Non-Target
Trunk	Internal and External Obliques, Erector Spinae, and Rectus abdominis	Trunk rotation and posture stabilization	Both
Shoulder	Internal rotation	Pectoralis major	Non-Target
	Shoulder stabilization and abduction	Infraspinatus/ Teres Minor	Non-Target
	Internal Rotation	Subscapularus	Non-Target
	Shoulder stabilization	Trapezius	Non-Target
	Shoulder stabilization/adduction	Latissimus dorsi	Non-Target
Hip	Hip Abduction	Gluteus medius/minimus	Non-Target
	Hip rotation	Hamstrings	Both
Knee	Maintain angle	Hamstrings, Quadriceps	Both

Table 2.4: Muscles Used in the Golf Swing (Acceleration)

Joint	Action	Muscle	Side
Wrist	Ulnar deviation (return from wristcock)	*Extensor and Flexor Carpi Ulnaris/carpi radialis longus/brevis	Both
Radio-Ulnar	Pronation	Pronator teres, pronator quadratus, brachioradialis	Non-Target
	Supination	Supinator, biceps brachii, brachioradialis	Target
Elbow	Arm Extension	Triceps	Non-Target
Shoulder	Internal rotation	Pectoralis major, subscapularus	Non-Target
	External Rotation	Infraspinatus/ Teres Minor	Target
	Shoulder stabilization/adduction/ Internal Rotation	Latissimus dorsi	Non-Target
	Trunk rotation and posture stabilization	Internal and External Obliques, Erector Spinae, and Rectus abdominis	Both
Trunk	Trunk Side Bend	Quadratus Lumborum	Non-Target
	Abduction/rotation/Lateral shift	Gluteus medius/minimus	Non-Target
Hip	Lateral weight shift to target	Hip Adductors (Brevis, longus, magnus)	Non-Target
	Hip rotation and extension/posture stabilization	Hamstrings	Both
	Push off/stabilization (Extension)	Gastrocnemius/soleus	Both
Knee			

*Some research suggests return from wrist cock (ulnar flexion) is solely due to transfer of angular momentum and no muscle force is required [108]

Table 2.5: Muscles Used in the Golf Swing (Follow-through)

Joint	Action	Muscle	Side
Wrist	Control of Radial Deviation	*Extensor and Flexor Carpi Ulnaris/carpi radialis longus/brevis	Both
Radio-Ulnar	Pronation	Pronator teres, pronator quadratus, brachioradialis	Non-Target
	Supination	Supinator, biceps brachii, brachioradialis	Target
Elbow	Flexion	Biceps Brachii	Target
Shoulder	Internal rotation	Pectoralis major, subscapularus	Non-Target
	Control of Internal Rotation	Infraspinatus/ Teres Minor	Non-Target
	Control of External Rotation	Subscapularus, Pectoralis major	Target
Trunk	Control of Trunk rotation and posture stabilization	Internal and External Obliques, Erector Spinae, and Rectus abdominis	Both
Hip	Hip Abduction/rotation/ Lateral weight shift	Gluteus medius/minimus	Non-Target
	Lateral weight shift to target	Hip Adductors (Brevis, longus, magnus)	Non-Target
	Hip rotation and extension/posture stabilization	Hamstrings	Both
Knee	Push off/stabilization (Extension)	Gastrocnemius/soleus	Both
	Stabilization	Tibialis anterior	Target

What are the energy sources that need to be trained for golf?

The golf swing is a brief, explosive movement. During the actual golf swing, primarily the ATP-phosphocreatine source energy source is used. Glycolytic and aerobic demands are seemingly low. However, increased muscular and aerobic endurance may be valuable when walking 18 or 36 holes or reducing fatigue-related conditions during extended practice sessions. Additionally, there may be some intangible benefits related to aerobic fitness, such as increased confidence, concentration, and more optimal stress response [130].

What type of muscle action should be used when training for golf?

Concentric, eccentric, and isometric muscle contractions are used during the golf swing. Trunk and shoulder musculature eccentrically contract during the follow through phase of the swing. Isometric contractions maintain posture during the swing and stabilize wrist, shoulder, and elbow joints. Concentric contractions of trunk rotators, pectoralis major and internal rotators of the arm are most important during the acceleration phase of the swing.

What are the primary sites of injury for golfers?

Although the primary purpose of a resistance-training program may be improved performance, it is important to identify and consider potential sites and possible causes for injury related to the sport [44]. Though golf is not thought of as a rigorous sport, many golfers may incur injury due to poor technique or overuse in the areas of the trunk, shoulder, wrist, and elbow. Several investigators have described the epidemiologist of golf injuries.

Shoulder

Shoulder injuries make up only 7 to 10% of all golf-related injuries. At the top of the backswing, when the target arm is maximally adducted, the head of the humerus may be impinged against the anterior labrum. During the acceleration phase of the swing the scapula provides a stable base for rotation of the humerus. If scapular muscles are incapable of maintaining this stable base, scapular lag may occur leading to injury. During the follow-through phase of the swing, the target humerus becomes horizontally abducted due to the momentum of the swinging clubhead. If shoulder muscles are incapable of controlling this abduction, the humerus may cause damage to the posterior labrum. Also, fraying of rotator cuff muscles may occur due to pinching by the labrum. Additionally, the non-target humerus achieves maximal horizontal adduction during the follow through. In this position the head of the humerus may impinge the anterior labrum if rotator cuff muscles are unable to control the momentum [11, 73, 123, 172].

Back

Back injuries are the most common (50 to 80 %) golf-related injury in both amateurs and professionals [123, 124]. Large lateral bending, shear, compression, and torsional forces have been detected in the lumbar spine during the golf swing. Amateurs create 80% greater shear and lateral bending forces in the lumbar spine than professionals [68]. Compression loads of eight times body weight are transmitted through the lumbar spine during the golf swing for both professionals and amateurs [68]. Peak torque in the lumbar vertebrae occurs just prior to impact [67].

Loads on the lumbar spine during the golf swing may cause muscle strain, herniated discs, or spondylolysis. Lumbar spinal compression loads during the golf swing are similar to loads observed to cause disc disruption in cadaveric studies [68]. As discs degenerate with age, loads may be transferred to vertebrae themselves. Shear loads recorded during the golf swing are near loads required to produce fractures in cadaveric studies and may cause injury to lumbar spinal bones [68].

Elbow

Professional golfers claim that 7% of their injuries are to the elbow, while amateurs claim 13-26% of all injuries are elbow injuries [11, 73, 123, 172]. The incidence of elbow injuries increases with number of rounds of golf per week. "Casting", or early release of non-target wrist cock, may contribute to medial epicondylitis (golfer's elbow). Lateral epicondylitis (tennis elbow) may occur in the target elbow and may be irritated by excessive forces and vibration transmitted through the club during off-center hits.

Wrists and Hands

In one study of professional golfers on the PGA tour, 134 of 393 (34%) injures were to the hands or wrist. The hands and wrists transmit the forces created by the unwinding of the trunk and the swinging of the arms into the club and ultimately the golf ball. The target wrist undergoes excessive motion during the golf swing. Maximal radial deviation occurs at the top of the backswing. The wrist moves through its entire range of motion by impact when it is forced into maximal ulnar deviation at impact. This catapulting action places extreme stress on the left wrist and fractures of the scaphoid or the hook of the hamate bones may occur due to compression from the butt of the club and transmission impact forces [132]. The most common overuse injuries are chronic sprains of the dorsal radiocarpal, distal radio-ulnar, and ulnocarpal ligaments. Tendonitis is also common in the abductor pollicis longus, extensor pollicis brevis and finger flexors and extensors [172].

Lower Extremity

Injuries to the lower extremity make up only 13 to 15% of all golf injuries and many of these are due to walking injuries or causes other than the golf swing motion [11, 73, 123, 172]. However, torque and compressive forces are evident at the hip, knee, and ankle joints during the golf swing.

Prevention of Golf-Related Injuries

There are several factors that may contribute to golf injuries: poor swing mechanics, overtraining, age, improperly fitted equipment, environmental hazards, insufficient warm-up prior to practice or play, and fitness level [161]. The golfer can minimize injury risk by preparing for environmental conditions, correcting improper swing mechanics, participating in a well-designed physical conditioning program, and ensuring proper fit of equipment. Investigators have promoted strength, flexibility, and endurance training to prevent golf injuries [142, 150]. Physical conditioning may have a greater impact on injury prevention in women versus men. A higher incidence in women of total and specifically upper extremity injuries has been noted [171]. Although no research has shown a cause and effect relationship between injury and physical conditioning, stretching and strengthening exercises may prevent muscle strains and tears, prepare muscles and tendons for performance, reinforce movement patterns, promote joint mobility and increase body temperature to all muscle groups. Stronger, more flexible muscles may also allow for more optimal swing mechanics, which would reduce stress on the musculoskeletal system.

Acute Program Variables

Based on the movement analyses of the golf swing, knee, hip, trunk, shoulder, arm, and hand muscles are active throughout the golf swing. Most contractions are concentric, however, isometric contractions are evident in shoulder girdle and postural stabilization, while eccentric contractions aid in slowing the body down in the follow-through phase of the swing. Any physical conditioning program should address each muscle group identified in the needs analyses. Rest periods should be 3-5 minutes because golf does not tax the glycolytic or aerobic energy systems, but will vary with goals of a periodized program.

Chronic Changes

The resistance training program may follow a traditional linear on non-linear periodization model. Golf is categorized as a power sport. The off-season is about 12 weeks long for tournament players, which will make up one mesocycle. Three four-week microcycles will be contained in the off-season mesocycle—hypertrophy, strength/power, and peaking. The golfers should enter a low-volume maintenance cycle as soon as the season starts. Training should be reduced to twice per week, with participants performing only structural or multijoint lifts at 1-5 RM load. A nonlinear program may be more feasible for competitive golfers due to long, split competitive seasons.

Anatomical Constraints

Too much muscle hypertrophy in the shoulders, chest and upper arms may be undesirable for golfers who already have large muscles in those areas. Shoulder range of motion may be inhibited by excessive muscle mass in these areas. Additionally, line of site to the ball may be blocked forcing posture to deviate from optimal. However, this is an extreme case and only extremely high volume resistance training programs along with genetic predisposition may lead to range of motion and line of site limitations. Generally, muscle hypertrophy should not hinder the swing and may help. Further research needs to be conducted in this area.

Flexibility Training

Recent research has documented the value of stretching alone and in combination with strength training for improved golf performance [74, 194]. Investigators have also reported the importance of maximizing the shoulder to trunk rotation relationship at the top of the backswing [22]. Based on EMG research, Jobe and colleagues (1994) formulated a stretching program for golfers [72]. They recommended exercises focused on stretching shoulder and trunk musculature. Stretching exercises should be performed daily after sufficient warm-up to avoid injury and maximize benefits.

Ballistic and Plyometric Training

Investigators have reported the importance of plyometric training in combination with traditional resistance training for explosive sport performance [110]. Specifically, one investigation documented increased gains in baseball bat speed when medicine ball rotational put training was combined with traditional resistance training programs [109]. Due to similarities in baseball and golf swings, it is reasonable to presume that such medicine ball put training may cause similar increases in golf clubhead speed.

Qualitative Analysis of the Golf Swing

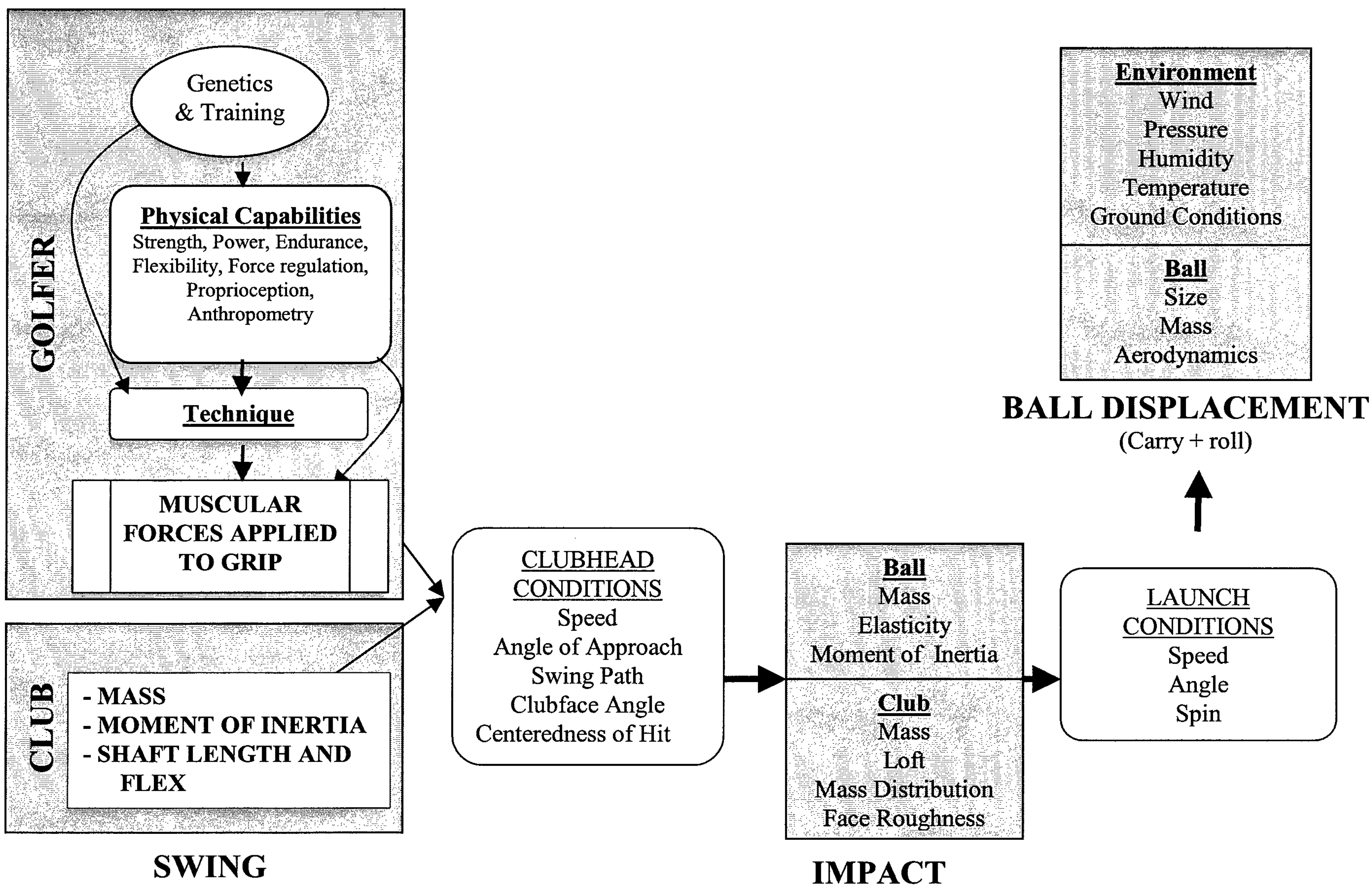
Qualitative analysis is a subjective method used to analyze performance of a motor skill [61]. Hay (1988) recommends developing a model to show the relationship between the result and relevant factors affecting the result [61]. See figure 2.2 for a qualitative analysis model of the golf shot.

The purpose of the following review of essential biomechanical elements of full golf swings is to develop an understanding of the golf swing for qualitative analysis. Full golf swings are executed to produce near maximal distance with a given club and this analysis excludes any less-than-full or short game swing. Before any golfer or instructor starts building an effective swing or troubleshooting one that's inefficient, he must understand the direct causes of ball flight—the goal of the swing. Everything in the golf swing should relate to distance and direction. A shot with perfect distance and direction would be a perfect shot—in the hole. To understand how the golf swing influences distance and direction, the dynamics of the ball-club interaction must be understood.

Gary Wiren (1990) identifies five physical laws assessed at the moment of impact that dictate distance and direction--speed, centeredness of hit, path, clubface angle, and angle of approach [201]. In a scientific approach to golf-swing training, all swing techniques must obviously be related back to these ball-flight laws. Speed of the clubhead will have a direct influence on the distance the ball will travel. The centeredness of the ball on impact with the clubface in relation to the percussion point will influence distance and direction. The path or direction of the arc of the clubhead away from and back to the ball is the primary influence on the direction of the ball flight. The degree at which the clubface is angled in relation to the swing path influences how much the ball will spin or curve—impacting distance and direction. The angle of approach of the clubhead to the ball influences backspin rate (affecting lift and drag) and therefore the distance the ball will travel.

These are absolute physical laws that determine the flight of the ball. However, when determining specific swing techniques for humans, there are not many absolutes. Investigators, coaches and golfers have spent countless hours searching for the key elements in the golf swing.

Figure 2.2: Qualitative Analysis Model for a Golf Shot (modified from figure 11-3[60] and figure 1[25])



Essential Biomechanical Elements of Golf Swings

Several investigators have attempted to identify important swing mechanics by simulating the golf swing with mathematical or mechanical models [24, 75, 102, 129]. The most common model is the "double pendulum". However, most golf-swing related scientific research has attempted to identify critical swing elements by comparing expert to novice golfers. Some of these investigators' findings may be useful in qualitative analysis of individual golf swings.

Some investigators have focused on the initial stages of the back swing. Kanwar and Chowgule (1994) observed that widening the on-plane swing arc of the right arm during takeaway produces significant improvements in distance, direction and trajectory. Similarly, Alpenfels (1994) reported that one of the five most common errors in amateur golfers is that they start the backswing too far to the inside of the proper plane of motion—caused by bending the right arm too quickly and pulling the club inside with the wrists. This error causes the amateur golfers to compensate elsewhere in their swing to create maximum speed, proper approach, and clubface angles by the time they get back to the impact position.

Study of the ground reaction forces and torques during the golf swing is another important factor to consider in maximizing golf swing performance. Proper foot-to-ground interaction has been recognized as the vital link that allows a golfer to perform the key movements that lead to maximization of club impact with the ball. The most general observation is that high skilled players shift their weight to the back foot during the backswing and to the forward foot during the downswing [186, 196]. Vertical force profiles showed that greater weight transfer, at a faster rate in the downswing, were characteristic of the low handicap golfer [86]. Pressure at the left mid-heel location started to increase approximately midway through the backswing, with a subsequent modest increase sustained until some time after the top of the backswing. At this point a very rapid increase in pressure was initiated which culminated in a peak value before rapidly decreasing again. The golfers who hit the longest drives also had the highest peak pressures, which were observed at the first metatarsal heads and occurred just before the ball impact. Skilled players have been observed to place their weight closer to their heels at the moment of contact, and to transfer vertical force from the back to front foot at a higher rate and slightly farther forward than a less skilled player. Less body rotation in high handicap golfers also results in a transfer of force to the anterior portion of the front foot [36].

Duration of the swing from takeaway to impact is another facet of the golf swing that is significantly different in high versus low skilled players. Robinson (1994) observed the time interval of the downswing to be the second most important determinant of clubhead speed at impact. Amateurs rotate more slowly than tour players on both the backswing and the downswing [112, 128]. The faster backswing could mean a more efficient connection between the arms and torso. Downswing time was 31% faster for tour pros, most likely resulting in greater clubhead speed. Possible explanations for the faster downswing are: faster change of direction, longer retention of wrist angle, more efficient swing path, and less hip slide. It is possible that just decreasing the duration of an unskilled golfer's swing from takeaway to impact will correct many other related technique problems and cause the overall motion to "fall into place". More research needs to be done in this area.

According to several studies, possibly the most important differentiation between skilled and unskilled golfers is wrist action in the down swing. Less skilled golfers allow the club to flail outwards early in the swing [29], which leads to various compensations. The final result is a much slower clubhead speed and a less than ideal swing path and angle of attack at impact. Investigators plotted velocity and acceleration over time curves for the downswing and less skilled golfers showed a very rough curve with peak values much before impact. Higher skilled golfers showed a smooth curve with peak acceleration and velocity curves at the instant of impact. The lower skilled golfers generated high forces possibly at a time in the forward swing when their bodies were least able to control them, thus, throwing the club out of plane and contributing to further swing error.

Robinson discovered that the single most significant swing characteristic identified in any category (related to clubhead speed) was the angle between the left forearm and the club or the wrist angle at the midpoint of the downswing when the left arm was parallel to the ground [158]. This characteristic alone predicted 60% of the variation in velocity, more than the cumulative percentage of any of the other categories of characteristics. McLaughlin and Best (1994) also demonstrated that the angle between the left arm and the club shaft at the middle of the downswing is one of the most significantly different parameters observed between skilled and unskilled golfers. Centrifugal forces generated by the pendulum action are used by better players to keep the clubhead on plane. Additionally, centrifugal force, rather than supination of the left wrist, provides the mechanism to square the clubface at impact [108].

Highly skilled golfers differ significantly from unskilled golfers in many areas and innumerable swing errors and compensations are possible for golfers of all skill levels. However, research seems to identify four primary differences as having the greatest impact on the five ball flight laws (and therefore distance and direction) identified by Wiren (1990): a wide backswing arc-specifically with the right arm, a more aggressive and earlier weight shift from the back to the front foot during the downswing, a faster time duration from take away to impact, and a delayed and then free release of the wrist cock in the downswing.

Measurement of Golf Ball Launch Conditions (GolfAchiever®)

The GolfAchiever® uses solid-state semiconductor laser technology to capture ball and club information in detail. Two lasers illuminating a series of photo detectors create a two-dimensional net. By applying a computer algorithm, instantaneous ball and club tracking are achieved using a three-dimensional space calculation with techniques of laser image recognition, mirror image rejection and image reconstruction. Focaltron Corporation has compared performance of the GolfAchiever with high-speed camera measurement to test measurement resolution (Table 2.6). Clubhead speed, ball take-off angle deviation, and clubface impact angle deviation were used for analysis in this investigation.

Table 2.6: GolfAchiever Physical Parameters and Resolutions (Modified from GolfAchiever Performance White Paper)

Physical Parameters	Measurement Resolution	Interpolated Resolution	Principle of Measurement
Swing Path	3 degrees	< 1.5 degrees	Laser image interpolation
Ball Speed	0.25%	<0.25%	Laser Image Section
Ball Take-Off Angle	1.5 degrees	<0.1 degrees	Laser positioning
Clubface Impact Angle	1.5 degrees	<0.1 degrees	Laser positioning
Club Head Speed	3.1%	<2%	Laser image interpolation
Club Head Impact Position	0.5 inch	0.25 inch	Laser image recognition
Ball Back Spin Rate	Approx. 10%	Approx. 5%	Laser positioning and angular momentum conservation
Ball Side Spin Rate	Approx. 20%	Approx. 10%	Laser positioning and angular momentum conservation
Carry Distance (down range) Total Distance (including offline)	4.9% 10.1%	<3% <7%	Aerodynamic calculation

Physiology of Stress

Pfister and Muir (1992) describe stress as the physical or emotional influences that disturb homeostasis of the organism and produces psychological and physiological changes in the organism [147]. As early as the 1930's, endocrinologist Hans Selye observed stimulation of animal adrenal glands when the animal was exposed to "stress"

[50]. The stress response has been described as a reaction of the body systems to a stimulus or stimuli that disturb homeostasis and is commonly known as the general adaptation syndrome (GAS) [83]. The GAS may progress in three stages: alarm reaction, resistance reaction, and exhaustion.

Alarm Reaction to Stressor

The initial step in the stress-response process is the perception of a stressor by the brain, which results in hypothalamic stimulation. The hypothalamus sends nerve impulses to the sympathetic centers in the spinal cord and the adrenal medulla is stimulated via the sympathetic nerves that release the neurotransmitter acetylcholine causing the adrenal medulla to release epinephrine and norepinephrine [174]. Classical "fight-or-flight" responses transpire in an effort to prepare the organism for emergency action.

Circulation is increased via increased heart rate and stroke volume in an effort to transport more blood (glucose and oxygen) to target muscles. Catecholamines cause constriction of blood vessels in skin and most viscera, while blood vessels of the heart, lungs, brain and active muscles dilate. Additionally, sympathetic stimulation increases sweating in many regions of the body. During a stressful episode, epinephrine and norepinephrine also cause dilation of the bronchioles of the lungs and the airway in order to make more oxygen available to the cell and to remove more carbon dioxide. Stimulation of the sympathetic nervous system inhibits activity in the gastrointestinal tract via the effect of norepinephrine on the neurons of the enteric nervous system and the smooth muscle of the digestive tract causing food movement throughout the gastrointestinal tract to slow down or stop [174]. Epinephrine and norepinephrine possibly reduce inhibitory mechanisms (Golgi Tendon)—decreasing neuromuscular inhibition and increasing strength of muscle contraction [198].

Activation of the sympathetic nervous system and secretion of catecholamines have been associated with effort level or arousal, while cortisol secretion has been associated with level of distress resulting in sadness, discouragement, etc. The sympathoadrenomedullary and hypothalamic-pituitary-adrenocortical (HPA) hormonal systems are regulated separately. As long as humans perceive themselves to be in control, the HPA axis is not activated [63].

Resistance Reaction to Stressor

The resistance reaction stage of stress response is longer-acting than the alarm reaction stage. The primary endocrine response to stress is increased activation of the hypothalamic-pituitary-adrenocortical-axis (HPAA) [43]. Stressor stimulation of the hypothalamus results in release of corticotropin-releasing hormone (CRH). Adrenocorticotrophic hormone (ACTH) release from the anterior pituitary is stimulated via the hypophysial portal circulation. Finally ACTH stimulates the adrenal cortex to release three groups of steroid hormones from the adrenal cortex: mineralocorticoids, androgens and glucocorticoids, which travel through the blood to many cells producing adaptations to the stressor [147, 166]. Release of CRF and ACTH during stressful events causes release of Beta-endorphins resulting in an analgesic, or pain reducing, effect [146].

Mineralocorticoids, primarily aldosterone, cause retention of sodium and water and increased elimination of hydrogen ion. The glucocorticoids include cortisol, corticosterone, and cortisone. However, cortisol is reported to be responsible for 95% of all glucocorticoid activity [174]. About 90% of cortisol in the blood is bound to plasma proteins, while 5 to 10% circulates unbound. The unbound or "free" cortisol is thought to be the biologically active form [84].

Increased levels of cortisol cause amino acids and fats to leave storage sites and enter the blood, making energy available for responses to stress. Cortisol protects against hypoglycemia, or a decrease in blood sugar, through various mechanisms acting in muscle, fat, and liver cells. Glucocorticoids also maintain sensitivity to epinephrine and norepinephrine and increase sensitivity to vasoconstrictor agents [50].

One study indicated that stress hormones play a role in the decline in muscle protein synthesis seen after trauma [191]. The results of the study indicated an effect due to stress hormones on the total ribosome concentration and on the relative abundance of ribosomes. In a similar, but separate study, investigators concluded that an infusion of stress hormones into healthy individuals produced changes in muscle amino acid metabolism similar to those observed after surgical trauma [192].

Cortisol may lower resistance to infection by temporarily inhibiting certain components of the immune system. Cortisol reduces blood concentration of eosinophils, basophils, and lymphocytes and decreases cellular immunity [50, 202]. Cortisol suppresses production of Interleukin-1, which stimulates production of immune substance by the liver, increases circulating neutrophils, and induces fever. Cortisol tempers or reduces the inflammatory process due to its ability to restrict blood flow, inhibit histimine formation and stabilize lysosomal membranes [50]. Rats subjected to repeated stressors had significant decreases in total number of mononuclear cells in spleen and blood [12]. The immune system activity limiting effect of cortisol may have an important role in reducing autoimmunity [15].

Testosterone

Although not typically associated with stress response, rises in testosterone have been associated with increased physical stress, such as short-term maximal exercise [88-90, 93], and psychological stress [52, 162]. Higher testosterone has also been associated with mood states such as competitiveness, drive, persistence, and contribution to winning [32, 63].

Release of testosterone, another steroid hormone, is controlled by the hypothalamus through gonadotropin-releasing hormone (GnRH). GnRH stimulates the anterior pituitary to release follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which in turn control release of testosterone from the Leydig cells of the testes. Normal young men produce about 7 mg of testosterone per day. Only 2% to 3% of blood testosterone is free, while most testosterone in the blood is bound to albumin or sex hormone-binding globulin (SHBG). Free testosterone is considered the physiological active form and diffuses out of blood vessels to act on target cells [50].

Obviously, the main physiological effect of testosterone is stimulation of sperm production and development of secondary male sexual characteristics to include bone and muscle growth [50]. Stress may have a negative effect on the reproductive system as CRH stimulates opioid secretion, which decreases gonadotrophic releasing hormone (GRH). Glucocorticoids also act directly at the testicle or ovary to inhibit responsiveness to luteinizing hormone [166]. Chronic stress may cause reductions in testosterone production [100].

One investigator compared psychological stress with serum testosterone concentration in 30-55 year-old men. Men with high psychological stress had lower testosterone concentration than those classified with low psychological stress. Cortisol concentration, however, was similar between groups [45]. Additionally, Nilsson and colleagues correlated low testosterone with psychosocial stress in middle-aged men, which may cause premature aging [139].

Cortisol, Testosterone, and Circadian Rhythm

Testosterone and cortisol are secreted in a circadian pattern. Hormone magnitude is greatest in the early morning hours and smallest in the late evening [84]. Walker and colleagues investigated the intraindividual variability of daily cortisol patterns and reported high stability of the pattern over 5 days [184]. Several investigations have confirmed the circadian pattern of testosterone secretion, especially with frequent samplings [107, 159, 164].

Testosterone and cortisol are steroid hormones synthesized in the adrenal and testes, respectively. Cholesterol forms the bases for steroid synthesis. Various modifications of the steroid nucleus determine its physiological activity [50].

Testosterone-to-Cortisol (T/C) Ratio

A correlation between cortisol increase and testosterone decrease was reported following a stressful stimulus [31]. Cortisol and testosterone are key hormones in protein metabolism. Cortisol promotes breakdown of muscle protein, while testosterone increases protein synthesis [3]. Therefore, testosterone-to-cortisol (T/C) ratio is a good indicator of anabolic/catabolic status. Investigators have suggested plasma testosterone to cortisol ratio as a marker of overtraining and plasma values below 0.35×10^{-3} or a decrease of the T/C ratio of 30% or more could be an indication of overtraining in aerobic endurance-type activities [1, 9]. T/C ratio decreases as exercise intensity and duration increase, as well as during intense training or competition periods [176]. Similar responses are caused by psychological stress during competition and authors recommend limiting of high intensity exercise and competition to avoid overtraining syndrome [177]. In a recent review article, Clow and Hucklebridge (2001) suggested endurance overtraining and chronic psychological stress to have similar effects [23]. Authors warned the synergistic effects of psychological and physiological stress might have detrimental effects on the immune system.

Convenience and Reliability of Salivary Cortisol and Testosterone

Saliva provides a noninvasive and very convenient means for measuring testosterone and cortisol. The introduction and validation of reliable salivary assays has greatly increased the spectrum of possible investigations [33, 181]. Previously, hormonal measurements in sport competition or daily acitvities were very difficult if not impossible. Also, medical personnel are required for blood drawing, while volunteers or subjects themselves can collect saliva. Additionally, the stress of venapuncture has been shown to increase stress levels, thereby affecting stress hormone measurements [134, 155, 175].

Reliability of saliva versus blood concentrations of testosterone and cortisol has been studied extensively [101, 155, 181, 182]. Specifically, Vining and colleagues reported salivary steroids to be independent of salivary flow rate and to show equilibrium with blood concentration [182]. One investigation reported perfect correlation of blood and saliva cortisol curves during exercise [152]. Vining and colleagues also reported a high linear relationship ($r = 0.84$) between salivary and serum unbound cortisol in men [181]. Another investigator studied the time difference in appearance of cortisol in the blood versus in the saliva. Walker and colleagues injected 5 mg of cortisol into subjects. Significant salivary cortisol concentration increases were noted within the first minute after injection and peak salivary values were detected within 1-2 minutes of peak cortisol detection in the blood [184]. The half-life of salivary cortisol has been reported to be between 58 and 113 minutes [41, 65].

In men, salivary testosterone is made up of 78% free or unbound testosterone, while serum testosterone is only 4% free [82]. Vittek and colleagues compared salivary and serum free and total testosterone measures and reported high and significant correlation of $r = 0.97$ between saliva and serum free testosterone [183]. Vining and colleagues also reported a high linear relationship ($r = 0.87$) between salivary and serum free testosterone in men [33].

Hellhammer and colleagues measured salivary testosterone in 20 men before, during and after different types of movies [62]. An increase in salivary testosterone was noted 15 minutes into erotic and sexual stimulation-type movies. A decline in salivary testosterone was noted during a stressful movie. Investigators concluded that salivary testosterone responds quickly to psychological stimulation and may, therefore, be used during psychological test situations.

Cortisol, Testosterone, and Athletic Competition

Several investigations have measured and reported endocrine response in association with athletic performance in competition [14, 38, 42, 49, 52, 59, 97, 126, 143, 144]. Most investigators have used testosterone and cortisol as dependent variables and assessed the effect of sports competition on pre-competition hormone measures or the effects of winning or losing on post-competition testosterone and cortisol measures.

Additionally, some investigations have used testosterone and cortisol as independent variables and associated pre-competition measures with following sports performance. Finally, some investigators have correlated perceived anxiety and mood psychometric measures to testosterone and cortisol measures before, during, or after competition.

Cortisol serum concentration may be elevated during and after athletic performance due to anticipation of or response to psychological stressors [6, 84, 115] or physical exertion of 70% of $\dot{V}O_2max$ or higher [35, 114]. One previous investigation (basketball players) reported no change in salivary cortisol from baseline to pre-competition [49]. However, other investigators have reported anticipatory cortisol rises prior to competition in tennis players [14], marathon runners [28, 59], pistol shooters [52], weight-lifters [143], and judo fighters [42, 169]. All previous investigations comparing post-athletic competition cortisol to baseline values have noted significant increases [38, 42, 52, 126, 144, 169].

Several previous investigators noted anticipatory testosterone rises prior to competition in tennis players [14], marathon runners [28], pistol shooters [52], and judo fighters [169]. Contrarily, testosterone did not rise prior to wrestling [144] or judo [42] competition. In fact, one previous investigation reported no rise in testosterone prior to a purely psychologically stressful event (skydiving) [21]. There is no apparent rationale for this disparity in results. It seems further investigation is required to understand the anticipatory response of testosterone to athletic competition.

Some investigators have also noted increases in testosterone from baseline measures to post-athletic competition [38, 52, 97, 169], while others have reported no change from pre to post competition [42, 143, 144]. Interestingly, all investigations reporting rises in testosterone from pre to post competition measured serum testosterone, while those reporting no change measured salivary testosterone. This may reflect differences between biocompartments and should be studied further.

Several investigators have also observed greater testosterone responses in winners compared to losers [14, 38, 47, 49, 119]. Most investigators attribute the increase to feelings of success or contribution to winning. Mazur's "biosocial theory of status" hypothesized a relationship between an individual's assertiveness to maintain status and testosterone concentration [118]. Competitive drive increases with rising testosterone. Testosterone also rises in response to winning or climbing in status in preparation of further competition.

Previous investigators have compared post-competition cortisol responses in winners and losers. Greater increases in cortisol from pre to post-competition have been noted in winners vs. losers [14, 38, 143, 169]. Passelergue (1995) also reported a low T/C ratio during competition, significantly lower T/C ratios in winners vs. losers, and a significant positive correlation between pre-competition cortisol response and performance [143]. See Table 2.7 below for a summary of studies reporting testosterone or cortisol response in relation to athletic performance.

Golf and Stress Response

Investigators report golf to require physical exertion of only 43% to 55% of $\dot{V}O_2max$ [111]. Therefore, any elevation in cortisol or testosterone during golf performance may be presumed to be the result of psychological stress. There is very limited research of stress response during competitive golf and its effects on performance.

One investigation measured salivary cortisol and heart rate prior to, during, and post competition and practice in 15 Professional Golfer's Association (PGA) pros (aged 21-25 years). Salivary cortisol and self-reported anxiety (CSAI-2) were measured prior to play and after holes 6, 12 and 18 during competition and practice. Salivary cortisol was also measured on baseline days. Higher cortisol concentration, heart rate, cognitive and somatic anxiety in competition versus practice was noted, but performance based on cortisol measures could not be predicted. Cortisol response and heart rate were not correlated with anxiety as measured by the CSAI-2 [126].

Another golf-related investigation measured performance and excretion of several neurotransmitters (norepinephrine, epinephrine, dopamine, and seratonin) under play, qualifying and competition conditions in 12 collegiate golfers. A significant sympathetic nervous system stress response during competition versus practice and different patterns of response for differing skill levels of golfers were noted [98].

One golf and stress response related longitudinal study investigated the relationship between pre-round competitive anxiety, performance, and post-round anxiety in seven collegiate women golfers [121]. The results of the investigation indicated no relationship between pre-round state anxiety, as assessed by the CSAI-2, and performance. However, performance was related significantly to post-round cognitive state anxiety and self-confidence. The conclusion that performance affects anxiety more than anxiety affects performance was also observed to be true in another investigation with golfers [27].

Table 2.7: Research reporting cortisol and/or testosterone measures in association with athletic competition

Investigation	Year	Sport	Dependent Variables	CM	Time of sample	Pre	Post	Winners vs. losers	Anxiety Correlation
Elias	1981	Wresting	C, T	B	10 min Pre/10 & 35 min post	No BL	+C, +T	+C, +T	
Cook et al	1987	Marathon	C, T	S	BL/ Imm. Pre/Every 4 mi/Post	+C, +T			
Booth et al	1989	Tennis	C, T	S	15 min. Pre/Imm. Post for 6 matches	+C, +T		+C, +T	
Harris	1989	Marathon	C, T, A	S	BL/ Imm. Pre/Post	+C		-	C+
Mazur	1992	Chess	C, T	S	Imm. Pre/Post	+Tw		+T	
Guezennec	1995	Pistol shooting	C, T, A	B	30-90 min Pre/10 min post	+C, +T	+C, +T		T+
Passelergue and Lac	1995	Wt lifting	C, T, T/C	S	30-90 min Pre/mid/post	+C, =T		-T/C, +C#	
McKay et. al	1997	Golf	C, CSAI-2	S	BL; 15 min Pre/post holes 6, 12, and 18	+C	+C	-	No
Suay et al	1999	Judo	C, T	B	BL/10 min Pre/10 min post fight	+C, +T	+C, +T	+C	
Gonzalez-Bono	1999	Basketball	C, T, Mood	S	BL/45 min Pre/15 min Post game	=C, =T	+C, =T	+T*	
Passelergue and Lac	1999	Wrestling	C, T	S	90 min Pre/Imm. Post/ 8 days post	+C, =T	+C, =T		
Kraemer et al	2000	Wrestling	C, T	B	BL, 10-30 min Pre/Post/5 days Post	=C, =T	+C, +T		
Kraemer et al	2001	Wrestling	C, T	B	BL/10-30 min Pre/Post	=C, =T	+C, =T	+T	
Filaire	2001	Judo	C, T, CSAI-2	S	BL/5 min Pre/5 min post fight	C+, =T	+C, =T		+C*

*BL = Baseline Day; # = significant correlation; T = Testosterone, C = Cortisol, T/C = T/C ratio, A = Anxiety, CM = Collection Method (B)lood or (S)aliva
+T* positively correlated with score to playing-time ratio
+Tw = pre-competition increase in winners only
+C* positively correlated CSAI-2 somatic and cognitive anxiety
+ Increased in comparison to baseline measure
= No change in comparison to baseline measure

Sport Competition Anxiety

There is some inconsistency as to the definition of anxiety, however one of the most accepted definitions was described by Charles Spielberger as: "emotional reactions that consist of a unique combination of: (1) feelings of tension, apprehension, and nervousness;

(2) unpleasant thoughts (worries); and (3) physiological changes". Spielberger goes on to discuss anxiety as a subjective, highly individual phenomena involving three components: stressors, self-evaluation or perception of the stressor, and emotional reactions to the stressor. A stressor that is perceived as threatening to one individual may be benign to another [55].

Several investigators have studied the effects of anxiety on sport performance. However, no single theory seems to explain the effects of anxiety on all types of sport performance. Two challenges exist in relating anxiety to sport performance: accurate and reliable measurement of anxiety and accurate and reliable measurement of actual sport performance [153].

Early research in the assessment of anxiety identified two separate, but related types of anxiety, trait anxiety and state anxiety [18]. Trait anxiety is a measurement of the predisposition of an individual to perceive situations as a threat. State anxiety depends on the intensity of the threat or stressor perceived by the individual and changes with the environment [153]. So, a person with a higher trait anxiety would likely respond to a stressor with higher state anxiety than a person with lower trait anxiety.

Most scientists investigating the relationship between anxiety and sports performance have used the Competitive State Anxiety Inventory-2 (CSAI-2) [113]. This anxiety-assessment tool separates anxiety into somatic anxiety and cognitive anxiety based on prior research showing the two as distinct components of anxiety [39]. The CSAI-2 also measures self-confidence. Reliability and validity of the CSAI-2 are discussed in depth by Martens and colleagues (1990) [113].

Martens and colleagues (1990) demonstrated cognitive state anxiety and state self-confidence are stable before competition, whereas somatic state anxiety quickly rises as competition nears. Additionally, interpersonal and situation factors influence changes in each component. Martens and colleagues (1990) also predicted a negative relationship between cognitive state anxiety and performance, a positive relationship between state self-confidence and performance and an inverted-U relationship between somatic state anxiety and performance. Better prediction of performance has been demonstrated in studies with intraindividual performance measures [51]. Process errors relate to cognitive anxiety state and output errors relate to somatic anxiety state. Some studies have reported no relationship between pre-competitive anxiety state and performance because anxiety state levels tend to drop once competition begins [99, 117, 121]. However, some investigators have noted a significant negative relationship between anxiety and performance, with winners generally reporting lower cognitive and somatic anxiety and higher self-confidence [17, 20, 51, 170].

Few studies have validated the CSAI-2 with physiological measures of anxiety. Yan Lan and Gill (1984) reported no relationship between heart rate and CSAI-2 components, while McAuley (1985) reported no relationship between somatic anxiety and cortisol response to competitive golf [121]. However, Filaire and colleagues reported significant correlations between somatic state anxiety, cognitive state anxiety and cortisol [42]. Similarly, other investigators have reported significant correlations between cortisol response and more general anxiety measures [59, 178].

Scoring methods for the CSAI-2 are explained in Martens and colleagues (1990) [113]. The cognitive anxiety state subscale is scored by totaling responses for 1, 4, 7, 10, 13, 16, 19, 22, and 25. The state self-confidence subscale is scored by adding items 6, 9, 12, 15, 18, 21, 24, and 27. The somatic state anxiety subscale is scored by adding items 2, 5, 8, 11, 14, 17, 20, 23, and 26 [113]. See Appendix C for CSAI-2 questionnaire.

Conclusions and Implications from the Literature Review

Golf is a multi-faceted sport and several different factors influence performance. There is an abundance of scientific research investigating golf swing mechanics and equipment. However, there is limited research investigating the effects of strength and conditioning on golfers, particularly elite men and women golfers. Additionally, there is little research investigating physiological stress during competitive golf.

It is clear from previous research that strength, power, and flexibility training has positive effects on recreational male golfers. However, the influence of strength, power, and flexibility training on elite men and women requires investigation. Additionally, previous investigations have focused primarily on only two golf variables—maximum distance and clubhead speed. A physical conditioning program may also affect putting performance and consistency, which are important to overall golf performance.

Previous investigations of the effects of resistance training on golf performance have not attempted to determine the causes of increased performance due to the training. Performance changes may be due to more optimal mechanics or simply increased strength and power. It's clear from the literature that the golf swing is a complex motion and subtle changes in technique may cause changes in impact conditions and subsequent performance.

Few studies have measured physiological variables in stressful situations outside of the laboratory. However, recent biochemical assay developments allow reliable salivary testosterone and cortisol determination. Salivary hormone values have also been highly correlated to serum values and have been repeatedly used to investigate endocrine response in the field.

Testosterone is an important hormone related to exercise and mood state. Several investigators have reported testosterone measures in association with sport performance, however results are inconsistent. Testosterone has never been measured in conjunction with golf performance and golf may illicit a different response than other sports or psychological stressors.

Similar to excessive high intensity exercise, a decrease in T/C ratio may occur in extended sports competition, which may slow recovery and cause overtraining symptoms. Competitive college golf lasts longer than most sports and golfers may be under endocrine stress for several hours during competition.

Psychometric tools are often used to assess state and trait anxiety. The relation of psychometric tools with physiological measures in real-life stressful situations is rare and valuable information. Research associating the CSAI-2 with competitive sport performance is inconclusive and further research is necessary to understand the psychometric measures relation to performance and endocrine response.

Chapter 3

Study #1: The Effects of Strength, Power, and Flexibility Training on Golf Performance in Competitive Intercollegiate Men and Women Golfers

I plan on submitting this chapter as a paper for publication to:
Medicine & Science in Sports & Exercise

- References, table, and figure placement will be reformatted to meet author guidelines

The Effects of Strength, Power, and Flexibility Training on Golf Performance in Competitive Intercollegiate Men and Women Golfers

Brandon K. Doan[1], Robert U. Newton[1], William J. Kraemer[3], Justin L. Cecil[2], Michael J. Fleck[2], Young-Hoo Kwon[4], Najma H. Javed[5], Thomas M. Harris[6]

[1]The Human Performance Laboratory, Ball State University, Muncie, IN 47306
[2]The Department of Athletics, Ball State University, Muncie, IN 47306
[3]The Human Performance Laboratory, Department of Kinesiology, The University of Connecticut, Storrs, CT 06269
[4]The Biomechanics Laboratory, Texas Women's University, Denton, TX 76204
[5]Department of Physiology and Health Science, Ball State University, Muncie, IN 47306
[6]Department of Management, Ball State University, Muncie, IN 47306

ADDRESS CORRESPONDENCE TO:

Brandon K. Doan
The Human Performance Laboratory
Ball State University
McKinley Ave.
Muncie, IN 47306

Phone: (765) 285-5178
Fax: (765) 285-3238
Email: Brandon_Doan@msn.com

Abstract

Several investigators have reported increased clubhead speed or driving distance following physical conditioning in recreational male golfers. However, the effect of physical conditioning on golf performance in elite-level men and women players is unclear from the literature. The purpose of this investigation was to determine the effects of a physical conditioning program (strength, power and flexibility training) on club head speed, consistency, and putting distance control in elite college-level men and women golfers. Subjects included ten men (age 19.8±1.7, body mass 74.5±9.0, height 178.8±5.6, competitive stroke average 76.0±1.4) and six women (age 18.5±0.8, body mass 63.5±4.1, height 169.5±3.9, competitive stroke average 89.0±2.2). Supervised strength, power, and flexibility training was performed 3 times per week for 11 weeks. Strength, power, and flexibility tests, golf ball launch conditions of a driver shot, and putting distance control, were conducted before and after the 11-week training period. A standard 1 RM protocol was used to test bench press 1 RM, while a regression equation was used to predict 1 RM based on 6 to 10 RM performance for lat pull, squat, and shoulder press. Measuring medicine ball release velocity with quantitative video analysis (Kwon 3D, Visol, Seoul, Korea) during a rotational medicine ball throw tested rotational power. Golf ball launch conditions were analyzed using a GolfAchiever by Focaltron®. Putting distance control was tested by measuring average distance variation for 15 4.6-foot putts. A qualitative swing analysis was performed for each player using Swinger® computer software. Significant ($p < 0.05$) increases were noted for all strength, power, and flexibility tests

from pre to post training: grip strength (7.3%); bench press (10.2%); lat pull (12.6%); squat (13.3%); and shoulder press (23.6%); rotational power (19.9%); and trunk rotation flexibility (12.3%). Clubhead speed also increased significantly (1.6%) from pre to post training. No significant differences were observed between pre and post-training values for clubface-angle or launch-angle deviation. Putting distance control significantly improved from pre to post-training for the men-only group (29.6%), while there was no significant difference in putting distance control for the total and women-only groups. Pearson r correlation analysis resulted in only one significant ($p < 0.05$) correlation in the men-only group between clubhead speed and rotational power ($r = 0.86$). The qualitative video analysis did not show any consistent trends in swing mechanics alterations. Assuming all other impact variables remain constant, the increase in clubhead speed from 47.3 to 48.0 m/s equating to approximately a 4.9-meter increase in driving distance. These results indicate that 11 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. Strength and power appear to be an important factor in generating clubhead speed, and skilled men and women golfers should engage in weight training, stretching, and rotational power training to improve golf performance.

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 10^{th} in total participation when compared to all other sports and recreational activities [133]. The total number of golfers in the United States has increased by 10% since 1995.

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, gender, and 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 where 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. Investigators, 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 [36]. Investigators and 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 [179, 195]. 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 as increased strength and flexibility allow more optimal mechanics, as well as longer, more effective practice sessions. Lastly, increased physiological function may reduce fatigue in competition and allow better response to the stress of competition [130].

Golf is a bilateral sport and studies using EMG have shown significant activity in a majority of the muscles of the body [13, 70, 71, 80, 131, 148, 149, 188]. Despite these findings, until recently, a 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 [64, 74, 103, 106, 168, 190, 193, 194]. 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%, while flexibility improved 7 to 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 [75]. Additionally, measurable performance gains and adaptations require more intense training in highly skilled versus novice athletes [56, 57, 167] and estimated gains in novice performance may not apply to elite athletes [66]. The influence of strength, power, and flexibility training on elite men and women requires investigation.

The effect of resistance training on elite or competitive-level women golfers has not been investigated. Women's professional golf is much newer then men's and strength training has been traditionally less acceptable among women compared to men. Differences between men and women in upper body strength and body composition suggest possibly different effects on performance [104, 197]. Driving distances for women are significantly shorter than men and any improvement in driving distance may play a more important role in overall golf performance.

Driving distance is an important ingredient in overall golf performance and has been positively correlated with score in average golfers ($r = 0.64$) [156] and elite golfers ($r = 0.49$ to $r = 0.84$) [58]. In a statistical comparison of performance variables for the 1995 PGA Tour, only driving distance and total driving (distance and accuracy) measures were significantly different ($p < .05$) between the top and bottom 10 money winners [40]. Cochran and colleagues (1968) studied the performance of a group of professional golfers playing in a professional tournament [24]. They concluded that a 20-yard 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, while doubling the accuracy of putting would save

4.2 strokes per round. A single stroke difference during a 72-hole tournament on the PGA tour is worth about $8,000 [122]. Physical conditioning may also improve performance in the short game [190] and reduce fatigue-related declines in performance.

The effects of resistance training on distance control in putting have not been previously studied. Increased strength of postural muscles may allow a more stable platform for execution of the putting stroke. Additionally, improvement in motor unit recruitment and firing patterns has been noted with resistance training, which may improve regulation of force [16]. Distance control is essential in any less-than-full length golf shot. Overall golf performance would be enhanced, especially since an average of 40% of all golf shots in an 18-hole round are putts [53].

The effects of resistance training on consistency have not been studied. Resistance training will improve muscular strength and local muscular endurance [5], which may have an impact on golf swing consistency during an 8-hour, 36-hole round of competitive golf where 130 or more golf shots may be executed. Consistency is an important factor in a target-oriented individual sport like golf where 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, consistency, and putting distance control in elite collegiate men and women golfers.

The following hypotheses were examined in this investigation.

Following strength, power and flexibility training:

1. Strength, trunk power, and trunk flexibility will increase

2. Swing mechanics will not change
3. Clubhead speed will increase
4. Consistency will not change
5. Putting distance control will improve

Methods

Subjects

Subjects included ten men and six women varsity golf athletes. 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.

Table 3.1: Strength Study Subject Demographics (values are mean and S.D.)

	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)

For the purpose of this investigation, competitive scoring average for each individual was an average of all competitive golf rounds for the 2000-2001 competitive golf season. Most of these collegiate players did not maintain an official USGA 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.

Experimental design

The experimental design was a longitudinal training intervention in which the adaptations in neuromuscular function, golf ball launch conditions, and putting distance control was 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.

Training Protocols

All subjects completed the same golf-specific resistance-training program designed in conjunction with the University Strength and Conditioning Staff. A thorough needs analysis was conducted to assure 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 (table 3.3). A certified strength and conditioning coach supervised the first two and last six weeks of training. Qualified supervision during strength training sessions is important as greater maximal strength gains have been noted in supervised versus unsupervised training [120]. Due to a university holiday, the middle three weeks of training were conducted 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 [74, 194]. Investigators have also reported the importance of maximizing the shoulder-to-trunk rotation relationship at the top of the backswing [22]. Based on EMG research, Jobe and colleagues (1994) formulated a stretching program for golfers [72]. They recommended exercises focused on stretching shoulder and trunk musculature (Table 3.2). Stretches were completed at end of strengthening program. Two sets of each exercise held for 15 seconds. Programs A and B alternated every other workout.

Table 3.2: Flexibility program (adapted from Jobe et al., 1994)

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 Sag

*Stretches completed at end of strengthening program.

The training program was performed three 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 3.4). Next, the resistance-training program was completed (Table 3.3) followed by the stretching program (Table 3.2). Subjects were also required to practice supervised golf-specific skills (hitting balls at a driving range and putting) for a minimum of eight hours per week during the training (Table 3.2).

Table 3.3: Pre-season strength and conditioning program

MONDAY

Exercise	**Sets X Reps (Wk 1-5)**	**Sets X Reps (Wk 6-11)**
*Trunk Routine		
Incline Bench Press	3 X 10-12	3 X 7-9
Bent Arm Pullover	3 X 10-12	3 X 7-9
Machine Upright Row	3 X 10-12	3 X 7-9
Leg Curl	3 X 10-12	3 X 7-9
Back Extensions	3 X 10-12	3 X 7-9
Dumbbell step-ups	3 X 10-12	3 X 7-9
Med. Ball Speed Rotations	2 X 15 secs	3 X 15 secs
Med. Ball Standing Throws	2 X 10	4 X 8

WEDNESDAY

*Trunk Routine		
Bench Press	3 X 10-12	3 X 7-9
Low Cable Row	3 X 10-12	3 X 7-9
Dumbbell Military Press	3 X 10-12	3 X 7-9
Leg Curl	3 X 10-12	3 X 7-9
Seated Good Mornings	3 X 10-12	3 X 7-9
Parallel Squat	3 X 10-12	3 X 7-9
Med. Ball Speed Rotations	2 X 15 secs	3 X 15 secs
Med. Ball Seated Throws	2 X 10	4 X 8

FRIDAY

*Trunk Routine		
Dumbbell Bench Press	3 X 10-12	3 X 7-9
1 Arm Dumbbell Row	3 X 10-12	3 X 7-9
Dumbbell Shoulder Circuit	3 X 10-12	3 X 7-9
Dumbbell Lunges	3 X 10-12	3 X 7-9
Leg Extensions	3 X 10-12	3 X 7-9
Back Extensions	3 X 10-12	3 X 7-9
Wrist Curls	3 X 10-12	3 X 7-9
Med. Ball Speed Rotations	2 X 15 secs	3 X 15 secs
Med. Ball Standing Throws	2 X 10	4 X 8

Table 3.4: Trunk Strengthening program

Monday

Exercise	**Week 1-2**		**Week 3-4**		**Week 5-6**		**Week 7-8**	
	sets	**reps**	**sets**	**reps**	**sets**	**reps**	**sets**	**reps**
Bent knee crunches	1	20	1 1	20 15	2	20	2	25
Back crunches	1	15	1 1	15 12	2	15	2	20
Straight leg crunches	1	25	1 1	25 20	2	25	2	30

Wednesday

Exercise	**Week 1-2**		**Week 3-4**		**Week 5-6**		**Week 7-8**	
	sets	**secs**	**sets**	**secs**	**sets**	**secs**	**sets**	**secs**
Isometric Pillar Bridges	2	30	2	30	2	35	2	40

Friday

Exercise	**Week 1-2**		**Week 3-4**		**Week 5-6**		**Week 7-8**	
	sets	**reps**	**sets**	**sets**	**reps**	**reps**	**sets**	**reps**
Jackknife opposites	1	24	1 1	12 10	2	12	2	15
Russian Twists	1	24	1 1	12 10	2	12	2	15
Alternate toe touches	1	15	1 1	15 10	2	15	2	20
Back crunch with twist	1	12	1 1	12 10	2	12	2	15

Medicine Ball Training

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 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.

Seated throws: In order to maximize torso-to-hip stretch and isolate torso power, subjects were seated on the floor holding 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.

Medicine Ball Speed Rotations: Two subjects were seated or standing back to back about one-half of a meter 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

1-RM Strength Testing

Before baseline strength testing, two familiarization sessions were performed to familiarize all subjects with lifts and teach proper technique. Immediately prior to each strength testing session, the subjects warmed-up with 2 sets of 8 repetitions at 30%-50% of their estimated 1-RM. Subjects were allowed adequate rest (2 - 3 minutes) between warm up sets and maximum attempts. Lifting technique was closely monitored and enforced by certified strength coaches.

The bench press was determined based on a true 1-RM test, in which progressively higher loads were lifted one time until an additional increase in load could not be lifted. The previously completed lift was recorded as the 1-RM.

Per university athletic weight room policy, the 1-RM squat, shoulder press and lat-pull strength was estimated based on repetition to fatigue tests in lieu of true 1-RM testing. The squat test was conducted using a load that was designed to elicit neuromuscular failure between 4 and 6 repetitions. The shoulder press and lat-pull tests used a load designed to elicit muscle failure between 7 and 10 repetitions. The subjects performed as many repetitions at the selected weight as possible, and this number was recorded as the number of repetitions to fatigue. The load and number of repetitions to fatigue were then plugged into the Brown Equation to calculate a predicted 1-RM [105]. 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.

Grip strength

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 three maximal trials from the left hand was used in data analysis [205].

Rotational Power

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 where the ball did not hit the target were discarded. Each throw was video taped with a JVC 9800 digital video camera 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, 2nd order Butterworth low-pass filter and converted to real-life coordinates using 2-dimensional direct linear transformation (DLT) [187]. Velocity at ball release was then calculated and three trials were averaged for statistical analysis (Figure 3.1).

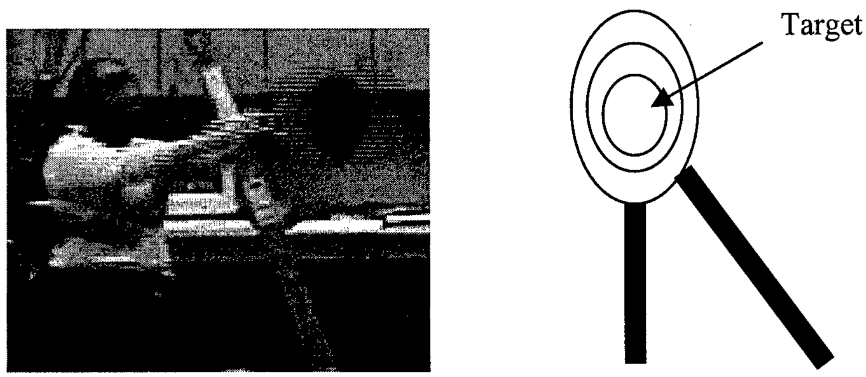


Figure 3.1: Medicine ball rotational put test.
Video-taped at 240 Hz, leading edge of ball digitized, and resultant velocity at release calculated.

Flexibility Testing

Maximum trunk rotation in both directions was measured using video analysis. A video camera 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-meter long board across their shoulders and were instructed to rotate their trunk to the end of their range of motion and hold for three 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, and then analyzed using Swinger® computer software. 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 counter clockwise (follow-through direction) trunk-rotation mean (figure 3.2).

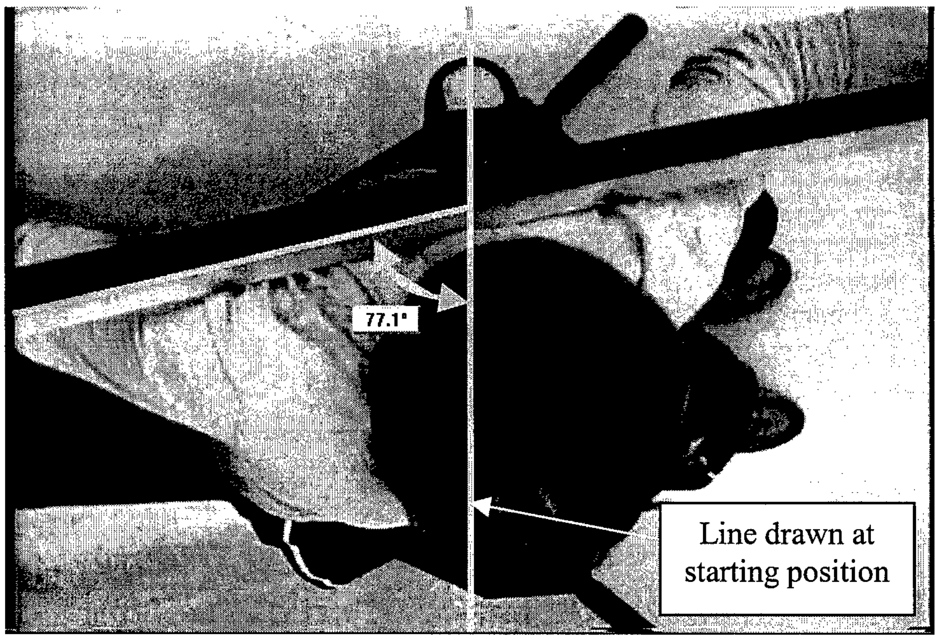


Figure 3.2: Trunk rotation flexibility test.
Angle between starting position and maximal rotation measured using Swinger® computer software. Three trials in each direction averaged for statistical analysis.

Qualitative Video Analyses

The last three 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 video camera (Model GR-AX76). This order was chosen to conserve time and videotape during data collection and there was little deviation expected between trial due to the high skill levels of the golfers. Shutter speed was set at 1/2000 of a second. Qualitative analysis for each subject was performed using Swinger (Victoria, Australia) computer software to overlay pre- and post-training swing images and identify changes in critical swing elements from pre to post testing.

Golf Ball 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 post testing. Golf ball 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 3.3). The GolfAchiever® uses solid-state semiconductor laser technology to capture ball and club information in detail. In order to discount mishits, the five 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 [24]. 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 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 [201].

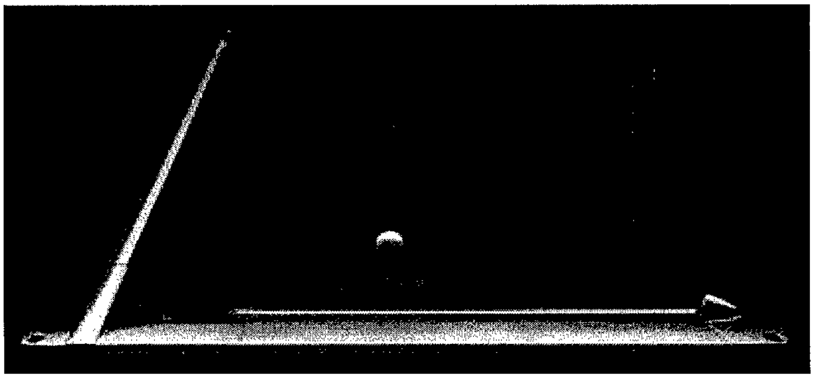


Figure 3.3: GolfAchiever

Putting distance control tests

There are two key elements to putting—distance and direction. Distance control, or touch, has been identified as the more difficult and important element to successful putting [145]. Subjects putted 15 balls to a line perpendicular to the intended direction of the ball 4.6 meters from the starting position on an indoor putting green (Figure 3.4). The putt was straight and flat. Mean deviation from the 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 two to four days prior to the pre-testing session.

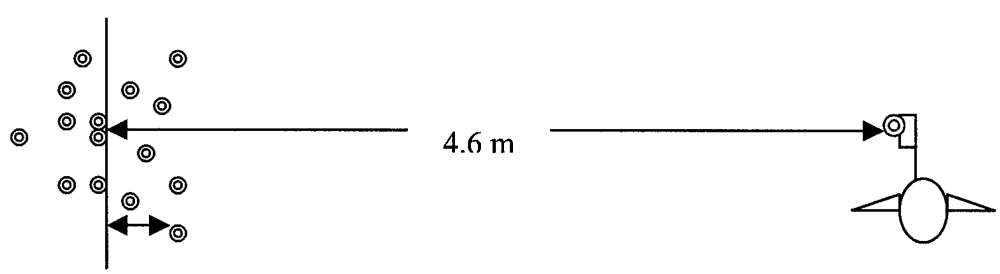


Figure 3.4: Putting Distance Control Test.
Putting Score = Average perpendicular distance from each ball to target line for 15 putts

Statistical Analyses

Repeated measures analysis of variance (ANOVA) was used to determine differences between pre and post-training means. A Pearson correlational analysis was used to test relationships among variables. Significance in this study was defined as $P < 0.05$.

Results

For all groups, all strength, power, and flexibility measures significantly increased between pre and post-training (Table 3.5). For the entire group clubhead speed significantly between pre and post-training, while putting distance control deviation decreased significantly for the men. Face and launch angle did not change significantly from pre to post-training (Table 3.6)

Table 3.5: 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 ±	Difference	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 ($p < .05$) difference was observed between pre and post conditions

Table 3.6: Summary of the effects of the physical training program on golf performance

VARIABLE		PRE		POST		POST - PRE		% Difference	p value
		Mean	SD ±	Mean	SD ±	Mean	SD ±		
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**	*7.98*	**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 ($p < .05$) difference was observed between pre and post conditions

Strength Testing

As hypothesized, grip strength, bench press 1 RM, estimated squat 1 RM, estimated lat pull 1 RM, and estimated shoulder press 1 RM were all significantly greater for all groups following the 11 weeks of strength training (Figure 3.5).

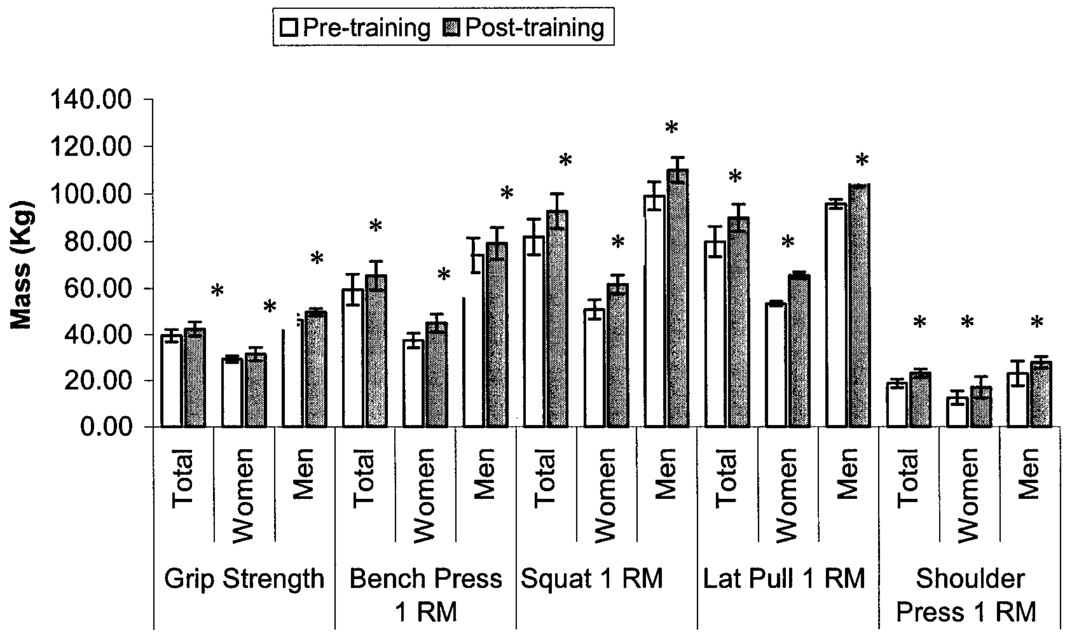


Figure 3.5: Strength measures for pre and post-training. Values are means (± S.E.). * A significant ($p < .05$) difference was observed between pre- and post-training conditions for all exercises

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 3.6).

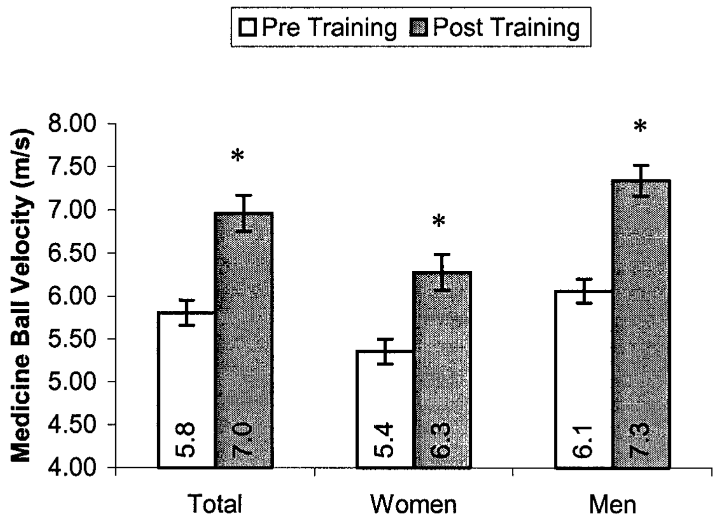


Figure 3.6: Rotational power (medicine ball put release velocity) means (± S.E.) for pre- and post-training.
* A significant ($p < .05$) difference was observed between pre and post-training conditions

Flexibility Testing

As hypothesized, trunk rotation flexibility in the back-swing and follow-through direction was significantly greater for all groups following the strength, power, and flexibility training protocol (Figure 3.7).

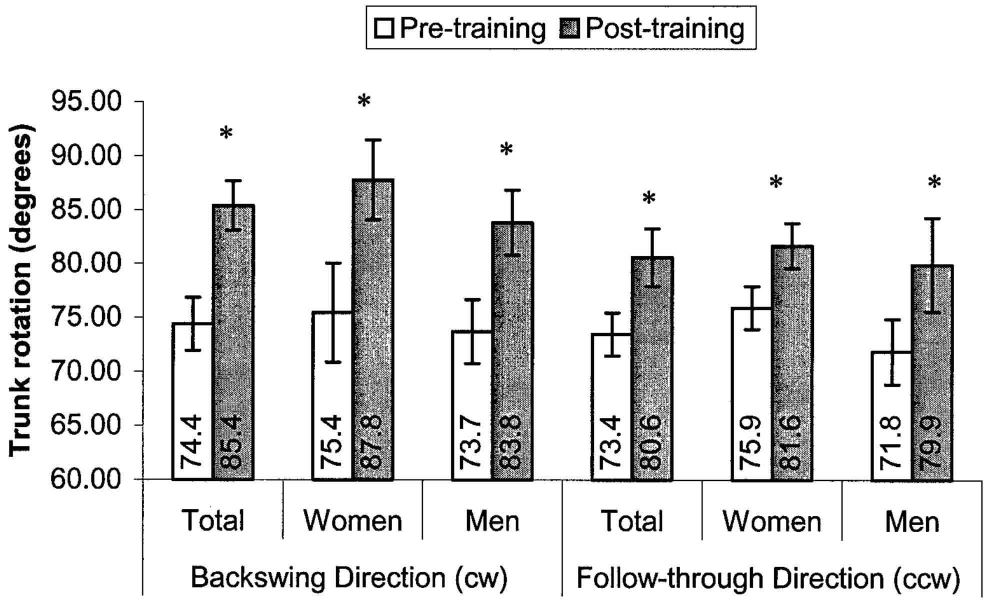


Figure 3.7: Trunk flexibility means (± S.E.) for pre and post-training.
* A significant ($p < .05$) difference was observed between pre- and post-training conditions

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 post-training. No obvious swing changes were noted in three of the women and two of the men subjects. Two of the women subjects appeared to have a greater transfer of weight from non-target to target foot in post- compared to pre-swings, while one of the men appeared to have a greater transfer of weight from non-target to target foot in pre compare to post-training swings. One of the women maintained a more extended right arm during take-away and a greater "X-factor"[22], or difference between hip and shoulder rotation at the top of her back swing during the post-training video session. One of the men decreased extension of the right arm during take-away from pre- to post-training. Two of the men appeared to release the club later (allow the wrists to uncock later) in the pre- compared to post-training video session. One of the men had a decreased "X-factor" in the post- compared to pre-video session. Another one of the men maintained a better synchronization between his trunk rotation and arm swing in post- versus pre-swings. His arms lagged further behind his trunk in the pre-training swings.

Golf Ball Launch Conditions

As hypothesized, clubhead speed for the entire group was significantly ($p < 0.05$) higher following the training period (Figure 3.8). However, there were no significant differences between pre- and post-training clubhead speeds for the men-only or women-only groups. Contrary to hypothesis, no significant differences were demonstrated between pre- and post-training values for face-angle deviation or launch-angle deviation for the total, men-only, or women-only groups (Figures 3.9).

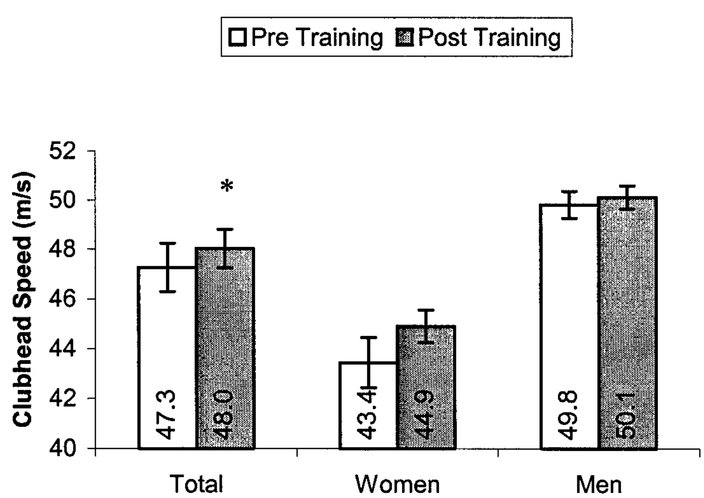


Figure 3.8: Clubhead speed means (± S.E.) for pre and post-training.
* A significant ($p < .05$) difference was observed between pre and post-training conditions

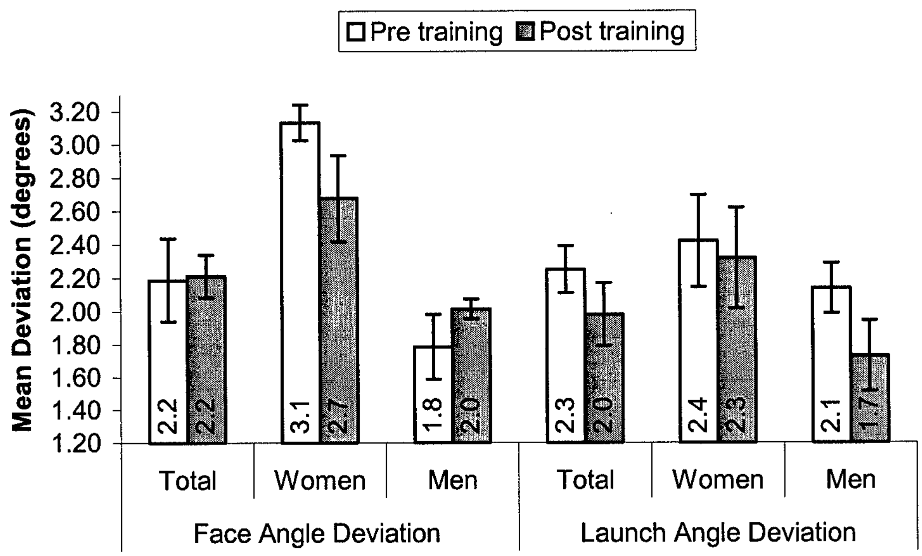


Figure 3.9: Launch and face angle deviation means (± S.E.) for pre- and post-training.

Putting distance control test

Contrary to hypothesis, there was no difference between pre- and post-training putting test values for the total group and the women-only group. However, the men-only group post-training putting test score was significantly lower than the pre-training putting score, indicating better putting distance control performance following the training (Figure 3.10).

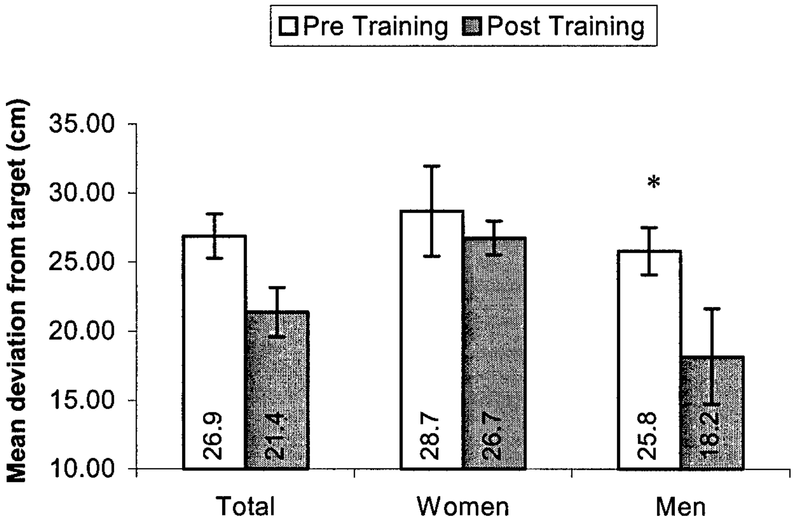


Figure 3.10: Putting distance control means (± S.E.) for pre and post-training.
* A significant ($p < .05$) difference was observed between pre- and post-training conditions

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

Clubhead Speed

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. If all other impact variables were held constant, this 0.7 m/s increase in clubhead speed equates to approximately a 4.9-meter increase in driving distance [24]. 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 ($r = 0.64$) [156] and elite golfers ($r = 0.49$ to $r = 0.84$) [58]. In a statistical comparison of performance variables for the 1995 PGA Tour, only driving distance and total driving (distance and accuracy) measures were significantly different ($p < .05$) between the top and bottom 10 money winners [40]. Cochran and colleagues (1968) studied the performance of a group of professional golfers playing in a professional tournament [24]. They concluded that a 17-meter 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-meter 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 an over $20,000 increase in tournament winnings or an over $500,000 increase in annual earnings over a 25-tournament season [122].

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 [160]. 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 [91]. 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 to 7% following resistance and flexibility training [64, 74, 103, 106, 168, 190, 193, 194]. 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 [56, 57, 167] and gains in novice performance may not apply to elite athletes [66]. 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 [75]. Strength, flexibility, and power gains may allow and encourage more optimal swing mechanics in novice players, while 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 [8, 44] 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 8-12 weeks, while 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 [109]. Finally, all strength and power measures were significantly higher following the training program in this investigation (Table 3.6; Figure 3.5). Relative strength (7 to 24%) and flexibility (7 to 16%) gains in this investigation were similar to previously reported strength (5% to 56%) and flexibility (7 to 39%) gains [64, 74, 103, 106, 168, 190, 193, 194]. 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 specific training. For this investigation, the strength, power and flexibility training was conducted during the off-season. Even though subjects were required to practice golf-specific skills a minimum of eight hours per week during the training, this may not have been enough to prevent a related decrease in golf performance. Initial testing was conducted two to three weeks following the regular season. During the regular season, golfers were required to practice and play golf five 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 did not change 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 post-training when the group was separated by gender, the women showed a trend toward an increase (3.36%) in clubhead speed, while the men's clubhead speed showed less of a trend towards an increase (0.61%) from pre- to post-training. 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 [173]. All six women increase clubhead speed from pre- to post-training, while 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 six months) untrained, however most of the men had some type of background in resistance training, while five of the six 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) NCAA Division I women's golf teams, while the men were ranked 132 out of 286 (the 54th percentile) NCAA Division I men's golf teams [7]. The increase in strength and flexibility may have allowed the women to adopt more optimal swing mechanics, while the men already used closer to optimal swing mechanics. However, no consistent trends were noted in either group when comparing pre- and post-swings using qualitative analysis.

Lastly, men have significantly more overall, and especially more upper-body, strength than women [104, 197]. 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 [204]. Additionally, the slower contraction velocities used in resistance training movements may not increase power production capabilities, especially in trained subjects [57, 77, 199]. Since golf requires high power outputs, more high velocity exercises may have caused more golf-specific adaptations.

Consistency

Consistency in this investigation was measured as the standard deviation of golf-ball launch and clubface angle for 15 driver shots. There was no change in these measures from pre- to post-training. 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.

Qualitative Video Analysis

The effect of specific swing elements on clubhead speed or golf ball launch conditions has not been investigated. However, several studies have compared novice players to experts and correlated different swing elements to clubhead speed [4, 79, 86, 112, 127, 128, 158, 186, 196]. No common trends in swing mechanics alteration from pre- to post-training 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 post-training may have existed. However, limitations in camera 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 three-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

Putting distance control significantly improved from pre- to post-training 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 allow 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 [16]. This is an important finding because an average of 40% of all golf shots in an 18-hole round are putts [53].

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 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/sec) 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 [129]. When medicine ball rotational put exercises were added to a resistance-training program for collegiate baseball players, bat speed significantly improved when compared to a resistance training-only control group [109]. Similarly, investigators have reported greater gains in vertical jump when ballistic training is performed in conjunction with traditional resistance training [125]. These results are also in agreement with EMG investigations that have noted high trunk muscle activation during golf swings [149]. 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 [138]. 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 with 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 to a non-periodized resistance training program [96]. 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 [8]. Collegiate, professional and amateur golf seasons are very long and split into two time blocks. Measuring effects of a year-round, including in-season, linear or nonlinear periodized training program would be valuable.

Other possible contributions of physical conditioning to golf performance

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. Resistance training has positive effects on bone, connective tissue and cardiovascular responses [26, 92].

These changes will influence quality of life and possibly have an effect on golf score, longevity, or injury prevention [142, 150]. 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 [189]. 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 [130].

Conclusion

Competitive, recreational, and especially collegiate golfers have limitations on practice time. It is valuable to know the effects of different training methods in order 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.

Chapter 4

Salivary Cortisol, Testosterone, and T/C Ratio Responses During a 36-hole Golf Competition

I plan on submitting this chapter as a paper for publication to:
Journal of Applied Physiology

- Table, and figure placement will be reformatted to meet author guidelines

Salivary Cortisol, Testosterone, and T/C Ratio Responses During a 36-hole Golf Competition

Brandon K. Doan[1], Robert U. Newton[1], William J. Kraemer[2], Young-Hoo Kwon[3], Najma H. Javed[4], Thomas M. Harris[5], Tim P. Scheet[2]

[1]The Human Performance Laboratory, Ball State University, Muncie, IN 47306
[2]The Human Performance Laboratory, Department of Kinesiology, The University of Connecticut, Storrs, CT 06269
[3]The Biomechanics Laboratory, Texas Women's University, Denton, TX 76204
[4]Department of Physiology and Health Science, Ball State University, Muncie, IN 47306
[5]Department of Management, Ball State University, Muncie, IN 47306

ADDRESS CORRESPONDENCE TO:

Brandon K. Doan
The Human Performance Laboratory
Ball State University
McKinley Ave.
Muncie, IN 47306

Phone: (765) 285-5178
Fax: (765) 285-3238
Email: Brandon_Doan@msn.com

Abstract

The purpose of this investigation was to study the effects of 36 continuous holes of competitive golf on salivary testosterone, cortisol, and testosterone-to-cortisol ratio and their relation to performance in elite male competitive collegiate golfers. Subjects were eight NCAA Division I men golfers with the following characteristics: age 20.3 (1.5) years; height 178.4 (4.5) cm; mass 75.5 (9.1) kg; competitive scoring average 76.4 (1.2) strokes per 18-hole round. 36 holes of a 54-hole NCAA Division I golf tournament with 15 participating teams were played on the first day of the competition. A saliva sample was taken 45 minutes prior to the round and immediately following each hole for a total of 37 samples per subject. Time matched baseline samples were collected on a different day to account for circadian rhythm. The Competitive State Anxiety Inventory-2 (CSAI-2) was used to assess pre-round self-reported state anxiety. Six-hole area under the curve (AUC) values were calculated for endocrine measures. Significant ($p < 0.05$) increases were noted for salivary cortisol during competition compared to baseline. Salivary testosterone did not change from baseline to competition. However, testosterone-to-cortisol (T/C) ratio was significantly lower throughout the competition compared to baseline measures. A high correlation ($r = 0.82$, $p < 0.05$) between 36-hole AUC testosterone-to-cortisol ratio difference and 36-hole score was noted. Additionally, there was a high correlation between pre-round testosterone ($r = 0.71$, $p < 0.05$) and T/C ratio response ($r = 0.82$, $p < 0.05$) and 36-hole score. Lastly, there was a strong positive correlation between CSAI-2 somatic anxiety ($r = 0. 81$, $p < 0.05$) and pre-round cortisol

response and a strong negative correlation between pre-round testosterone ($r = -0.80$, $p < 0.05$), T/C ratio ($r = -.72$, $p < 0.05$) and CSAI-2 somatic anxiety. These results indicate a significant hormonal strain during almost 10 hours of competitive golf. The CSAI-2 has been further validated by correlation with endocrine measures of stress. Good golf performance (low golf scores) in this competition was related to low T/C ratio.

Introduction

Pfister and Muir (1992) describe stress as the physical or emotional influences that disturb homeostasis of the organism and produce psychological and physiological changes in the organism [147]. As early as the 1930's, endocrinologist Hans Selye observed stimulation of animal adrenal glands when the animal was exposed to "stress" [50]. Stress response has been described as a reaction of the body systems to a stimulus or stimuli that disturb homeostasis and is commonly known as the general adaptation syndrome (GAS) [83].

Reliability of saliva versus blood concentrations of testosterone and cortisol has been studied extensively [101, 155, 181, 182]. Specifically, Vining and colleagues (1983) observed salivary steroids to be independent of salivary flow rate and to show equilibrium with blood concentration [182]. Investigators have reported high to exact correlation of blood and saliva cortisol curves during rest and exercise [152, 181]. Significant salivary cortisol concentration increases were noted within the first minute after injection and peak salivary values were detected within 1-2 minutes of peak cortisol detection in the blood [184], while the half-life of salivary cortisol has been reported to be between 58 and 113 minutes [41, 65].

In men, salivary testosterone is made up of 78% free or unbound testosterone, while serum testosterone is only 4% free [82]. Comparisons between salivary and serum free and total testosterone measures result in high and significant correlations ($r = 0.87$ to 0.97) between saliva and serum free testosterone [183]. Vining and colleagues also reported a high linear relationship (r = 0.87) between salivary and serum free testosterone in men [33].

Testosterone and cortisol are secreted in a circadian rhythm. Hormone magnitude is greatest in the early morning hours and smallest in the late evening [84]. Walker and Colleagues investigated the intraindividual variability of daily cortisol patterns and reported high stability of the pattern over five days [184]. Several investigations have confirmed the circadian pattern of testosterone secretion, especially with frequent samplings [107, 159, 164].

The primary endocrine response to stress is increased activation of the hypothalamic-pituitary-adrenocortical-axis (HPAA) [43]. Cortisol serum concentration may be elevated during and after athletic performance due to anticipation of or response to psychological stressors [6, 84, 115] or physical exertion of 70% of $\dot{V}O_2max$ or higher [35, 114]. One previous investigation (basketball players) reported no change in salivary cortisol from baseline to pre-competition [49]. However, other investigators have reported anticipatory cortisol rises prior to competition in tennis players [14], marathon runners [28, 59], pistol shooters [52], weight lifters [143], and judo fighters [42, 169]. All previous investigations comparing post-athletic competition cortisol to baseline values have noted significant increases [38, 42, 52, 126, 144, 169].

Although not typically associated with stress response, rises in testosterone have been associated with increased physical stress, such as short-term maximal exercise [88-90, 93], and psychological stress [52, 162]. Higher testosterone has also been associated with mood states such as competitiveness, drive, persistence, and contribution to winning

[32, 63].

Testosterone rises in anticipation of competition in tennis players [14], marathon runners [28], pistol shooters [52], and judo fighters [169]. Contrarily, testosterone did not rise prior to wrestling [144] or judo [42] competition. In fact, one previous investigation reported no rise in testosterone prior to a purely psychologically stressful event (skydiving) [21]. There is no apparent rationale for this disparity in results. It seems further investigation is required to understand the anticipatory response of testosterone to athletic competition.

Investigators have noted increases in testosterone from baseline measures to post-athletic competition in wrestling, pistol-shooting, and judo competition [38, 52, 97, 169], while others have reported no change from pre to post-wrestling or judo competition [42, 49, 143, 144]. Several investigators have also reported greater testosterone responses in winners compared to losers [14, 38, 47, 49, 119]. Most investigators attribute the increase to feelings of success or contribution to winning. Mazur's "biosocial theory of status" hypothesized a relationship between an individual's assertiveness to maintain status and testosterone concentration [118]. Competitive drive increases with rising testosterone. Additionally, testosterone rises in response to winning or climbing in status in preparation of further competition.

Previous investigators have compared post-competition cortisol responses in winners and losers. Greater increases in cortisol from pre to post-competition have been noted in winners vs. losers [14, 38, 143, 169]. Passelergue and colleagues (1995) also reported a low T/C ratio during competition, significantly lower T/C ratios in winners vs.

losers, and a significant positive correlation between pre-competition cortisol response and performance [143].

Cortisol and testosterone are key hormones in protein metabolism. Cortisol promotes breakdown of muscle protein, while testosterone increases protein synthesis [3]. Therefore, T/C ratio is a good indicator of anabolic/catabolic status. Investigators have suggested T/C ratio as a marker of overtraining and plasma values below 0.35 10^{-3} or a decrease of the T/C ratio of 30% or more could be an indication of overtraining in aerobic endurance-type activities [1, 9]. T/C ratio decreases as exercise intensity and duration increase, as well as during intense training or competition periods [176]. Similar responses are caused by psychological stress during competition and authors recommend limiting of high intensity exercise and competition stress to avoid overtraining syndrome [177]. In a recent review article, Clow and Hucklebridge (2001) suggested endurance overtraining and chronic psychological stress to have similar effects [23]. Authors warned the synergistic effects of psychological and physiological stress might have detrimental effects on the immune system.

Most investigators investigating the relationship between anxiety and sports performance have used the Competitive State Anxiety Inventory-2 (CSAI-2) [113]. This anxiety-assessment tool separates anxiety into somatic anxiety and cognitive anxiety based on prior research showing the two as distinct components of anxiety [39]. The CSAI-2 also measures self-confidence and reliability and validity of the CSAI-2 have been reported in depth [113].

Few studies have validated the CSAI-2 with physiological measures of anxiety.

Yan Lan and Gill (1984) reported no relationship between heart rate and CSAI-2 components [203], while McAuley (1985) reported no relationship between somatic anxiety and cortisol response to competitive golf [121]. However, Filaire and colleagues reported significant correlations between somatic state anxiety, cognitive state anxiety and cortisol [42]. Similarly, other investigators have reported significant correlations between cortisol response and more general anxiety measures [59, 178].

Investigators report golf to require physical exertion of only 43% to 55% of $\dot{V}O_2max$ [111]. Therefore, any elevation in cortisol or testosterone during golf performance may be presumed to be the result of psychological stress. There is limited research of stress response during competitive golf and its effects on performance. In one investigation, salivary cortisol and self-reported anxiety (CSAI-2) were measured prior to play and after holes 6, 12 and 18 during competition and practice in 15 Professional Golfer's Association (PGA) pros (aged 21-25 years). Salivary cortisol was also measured on baseline days. Higher cortisol concentration, heart rate, cognitive and somatic anxiety in competition versus practice was noted, but performance based on cortisol measures could not be predicted. Cortisol response and heart rate were not correlated with anxiety as measured by the CSAI-2 [126].

Another golf-related investigation measured performance and excretion of several neurotransmitters (norepinephrine, epinephrine, dopamine, and seratonin) under play, qualifying and competition conditions in 12 collegiate golfers. A significant sympathetic nervous system stress response during competition versus practice and different patterns of response for differing skill levels of golfers were noted [98].

Men's NCAA Division I golf teams play 12 or more tournaments each season and tournaments are normally played over two days with 36 holes played on the first day and 18 holes on the second day. The playing of 36 holes in one day was implemented to reduce the number of days of the competition, while maximizing the number of competitive rounds. As golf has become more popular, golf courses are less willing to allow collegiate golfers to take course time away from paying customers. Additionally, universities, coaches and players strive to minimize time away from class. Other amateur golf tournaments, such as the U.S. Amateur Championship require playing of 36 holes for several consecutive days.

An 18-hole competitive round lasts from 4 to 6 hours, while a 36-hole competitive round might last 8 to 12 hours. When metabolic demands are combined with the psychological stress of competition there may be a significant endocrine response to competitive golf, which may have an impact on performance, recovery, and long-term health.

The purpose of this investigation was to study the effects of 36 continuous holes of competitive golf on salivary testosterone and cortisol and their relation to performance in elite male competitive collegiate golfers. A secondary purpose was to relate pre-competition CSAI-2 measures of perceived anxiety to cortisol and testosterone response. The following hypotheses were examined in this investigation:

1. Salivary cortisol will be higher in golf tournament competition than a baseline condition.

2. Salivary testosterone will not change in golf tournament competition compared to a baseline condition.
3. T/C ratio will be lower in golf tournament competition than a baseline condition.
4. Perceived fatigue will be greater during competition than baseline.
5. Salivary cortisol will be negatively correlated to performance.
6. Salivary T/C ratio will be positively correlated to performance.
7. Pre-competition salivary cortisol will be positively correlated to pre-competition somatic anxiety as measured by the CSAI-2.
8. Pre-round salivary testosterone will be elevated in competition compared to baseline.
9. Pre-round salivary cortisol will be elevated in competition compared to baseline.

Methods

Subjects

Subjects were eight NCAA Division I men golfers with the following characteristics: age 20.3 (1.5) years; height 178.4 (4.5) cm; mass 75.5 (9.1) Kg.; competitive scoring average 76.4 (1.2) strokes per 18-hole round. Estimated handicap for all golfers was zero. The Institutional Review Board committee 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. Subjects were familiarized with sampling and survey procedures one to three days prior to the actual testing.

Data Collection Procedures

Competition samples were taken during an NCAA Division I golf tournament. Per NCAA requirements, all 80 players (15 teams) carried their own golf bag throughout the competition. The format for starting was a "shotgun" start so all subjects started the round at the same time of day on different holes. Pre-competition saliva samples were taken at 7:15 A.M., 45 minutes prior to teeing off on the first hole of the round. During the competition, a saliva sample was taken immediately following each hole for a total of 37 samples per subject during the 36-hole competition. Time between samples ranged from 10 to 25 minutes, with an average time between samples of 16 minutes (Figure 4.1).

Competition Sampling

Hole	Pre	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36

CSAI-2

1 – 3 weeks between competition and baseline sampling

Baseline Sampling

Time	7:15	8:20	8:35	8:55	9:13	9:35	9:50	10:05	10:15	10:25	10:45	11:00	11:15	11:35	11:55	12:10	12:33	12:50	1:00	1:20	1:35	1:50	2:05	2:30	2:40	2:55	3:05	3:21	3:36	3:53	4:12	4:25	4:40	4:54	5:12	5:25	5:35

Figure 4.1: Saliva sampling procedure.
Times are average time for end-of-corresponding hole and baseline sampling

One research assistant was assigned to each golfer for the entire 36-hole round. The research assistant carried 36 pre-labeled Sarstedt salivettes (model #D-51588, Newton, NC), stored in a small cooler on ice. Immediately following each hole, the research assistant provided a new salivette to the subject and recorded the time of sample, any food or drink ingested, as well as the subject's mental and physical fatigue using a visual analog scale (Figure 4.2).

1	2	3	4	5	6	7	8	9	10
Completely Exhausted									Maximum energy level

Figure 4.2: Fatigue Scale. Used after each saliva sampling.

Subjects were instructed to remove and replace the cotton wool swab from the salivette without using their hands and lightly chew on it for 45 seconds. Saliva samples were returned to the laboratory after 18 and 36 holes and centrifuged at 5000 rpm for 10 minutes to force saliva from the cotton swabs into the bottom of the salivettes. Saliva was then transferred to 1.5 mL eppendorfs and stored at -80° C for subsequent analysis.

Saliva was thawed and analyzed in the laboratory at a later date to compare cortisol and testosterone concentrations to baseline conditions and performance on the previous and following holes. Baseline saliva samples were collected on a different day within one to three weeks following the competition [84]. Timing of baseline samplings was matched to corresponding time of samplings during competition (Figure 4.1). Additionally, food and drink consumption were recorded during competition and replicated during the baseline collection. Subjects were instructed to abstain from sexual activity, alcohol, and caffeine the night before and the day of sampling.

Biochemical Analysis

Saliva was moved from -80° C to –20° 48 hours prior to analysis. 24 hours before analysis the saliva samples were moved to 0° C and were allowed to warm to room temperature immediately before analysis. Salivary testosterone concentration was determined in duplicate by Enzyme Immunoassay using a Salimetrics Salivary Testosterone Enzyme Immunoassay Kit (Catalog No. 1401/1402, State College, PA). Salivary cortisol concentration was determined in duplicate by Enzyme Immunoassay using a Diagnostic Systems Laboratories Salivary Cortisol Enzyme Immunoassay Kit (DSL-10-671000 ACTIVE, Webster, Texas). Assay plates were read using a Wallac 1420 Victor^2 Multilabel Reader (Turku, Finland). Intra-assay variance for cortisol was 2.51% and testosterone was 2.69%.

Competitive State Anxiety

Competitive state anxiety was assessed only on the competition day. 45 minutes prior to the round, subjects completed the CSAI-2. Subjects all completed a practice CSAI-2 one to three days prior to the competition for familiarization. The CSAI-2 is a 27-item written self-evaluation of state anxiety. The instrument assesses cognitive anxiety, somatic anxiety and self-confidence. Extensive research has been done using the CSAI-2 and it is a reliable and valid psychometric tool [113].

Data Analysis

Salivary testosterone and cortisol concentration, as well as T/C ratio differences were computed by subtracting baseline from competition values to account for individual circadian rhythm variations. These difference values were correlated to performance and CSAI-2 values using a Pearson Correlation ($p < 0.05$). Each player's 36-hole score was normalized by subtracting a handicap. Handicap was computed by subtracting each player's 36-hole season average score from the tournament average. Tournament average was computed as the mean 36-hole score of all 80 competitors. Score on each hole was normalized by subtracting a prorated handicap and the average score on each hole of all 80 competitors in the tournament from each individual's hole-by-hole score. Normalization of the scores allows more accurate assessment and comparison of individual performance.

Area under the curve (AUC) values for salivary testosterone and cortisol concentration, as well as T/C ratio, were approximated for the group by summing measures over six holes (6-hole AUC) and over the entire 36 holes (36-hole AUC) during competition and for each corresponding time period during the baseline day. For 6-hole AUC measures, a competition by hole or time period (2 X 7) repeated measures ANOVA was used to detect any differences between competition and baseline means. Separate baseline and competition data were analyzed using a competition by hole or time period (1 X 7) repeated measures ANOVA. A Fisher LSD post-hoc test was used to determine pairwise differences. Separate hole or time period by competition (1 X 2) repeated measures ANOVA's were used for pairwise comparison within each time period to determine where specific differences occurred between competition and baseline measures. A Pearson product moment was used to examine the relationship between individual hole, 6-hole AUC, and 36-hole AUC and corresponding golf score. The criterion for statistical significance was set at $p < 0.05$.

Experiment-wise error was not compensated for by adjusting alpha levels. The small sample size and large variation in physiological measurement and competitive performance measures makes it difficult to detect differences. This liberal approach was chosen to highlight possible differences due to the exploratory nature of the experiment.

Results

Salivary Cortisol

6-hole AUC values were used for statistical analysis. Significant competition vs. baseline effect ($F(1,7) = 4.73$, $p < 0.05$) and a significant hole or time point effect ($F(6, 42) = 24.26$, $p < 0.001$) was noted from the ANOVA. No significant interaction was noted between baseline or competition cortisol measures and time of day or hole.

Significant pairwise differences were noted between baseline and competition salivary cortisol measures at sample periods 1-6 through 25-30 (Figure 4.3). Additionally, baseline salivary cortisol at all subsequent sample periods was significantly lower than the pre-round baseline salivary cortisol. Baseline salivary cortisol at sample periods 7-12, 24-30 and 31-36 was significantly lower than baseline salivary cortisol during sample period 1-6. Competition salivary cortisol was significantly lower during sample periods 7-12, 13-18, 19-24, and 31-36 than the pre-round and hole 1-6 sample periods. Competition salivary cortisol during holes 13-18 was significantly lower than competition salivary cortisol during holes 7-12. Competition salivary cortisol was significantly lower during holes 31-36 than all other sample periods.

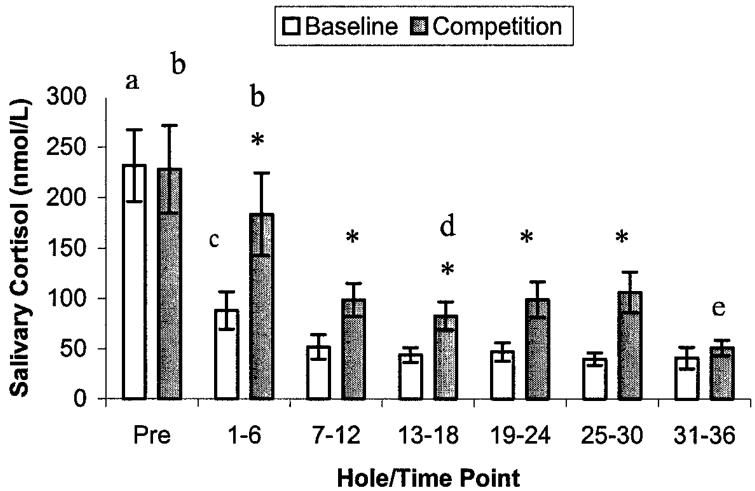


Figure 4.3: Salivary cortisol area under the curve (AUC) measures for a baseline and competition. Values are means (± S.E.).
* Significant ($p < 0.05$) difference observed between baseline and competition conditions during sample period. (a) Significant difference observed between pre baseline salivary cortisol all other baseline sample periods. (b) Significant difference observed between competition salivary cortisol sample periods pre and 1-6 and all other competition sample periods. (c) Baseline salivary cortisol at sample periods 7-12, 25-30 and 31-36 was significantly lower than salivary cortisol during sample period 1-6. (d) Significant difference observed between competition salivary cortisol sample periods 13-18 and 7-12. (e) Significant difference observed between competition salivary cortisol during sample period 31-36 and salivary cortisol during all other competition sample periods.

No statistical analysis was performed on individual sample period or hole samples. However the mean and standard error salivary cortisol values for each sample period are presented in figure 4.4. Figures for baseline and competition exhibit a normal circadian pattern, with afternoon samples being lower than morning samples [84].

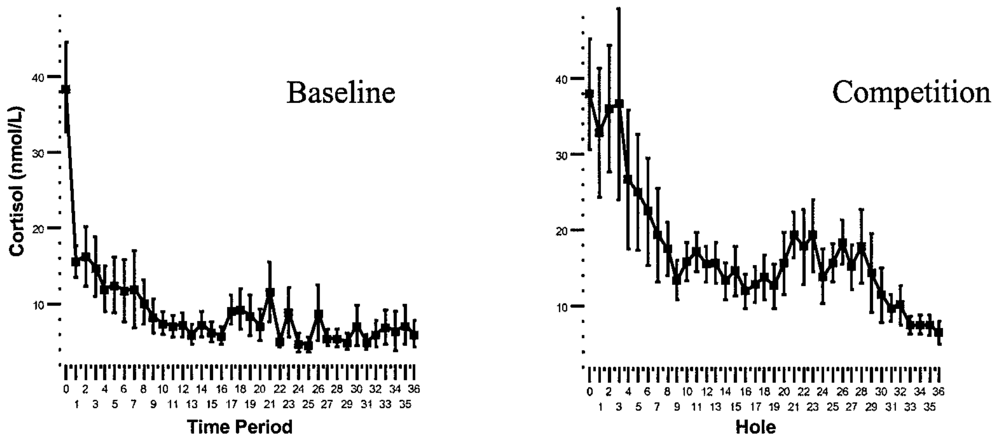


Figure 4.4: Salivary cortisol measures for baseline and competition. Values are means (± S.E.).

Salivary Testosterone

These 6-hole AUC values were used for statistical analyses. No significant competition vs. baseline effect was noted. However, a significant hole or time point effect ($F(6, 42) = 3.65$, $p < 0.003$) was noted from the ANOVA. No significant interaction was noted between baseline or competition testosterone measures and time of day or hole.

Figure 4.5 displays significant pairwise differences between pre-round baseline and competition salivary testosterone measures only at sample period 25-30. Additionally, pre and 1-6 sample period baseline salivary testosterone was significantly higher than sample periods 19-24, 25-30, and 31-36 baseline salivary testosterone. Also, sample period 1-6 baseline salivary testosterone was significantly higher than baseline sample period 13-18 salivary testosterone. No significant differences were observed between any sample periods for competition salivary testosterone. However, there is a trend toward a typical circadian rhythm as each competition sample period is lower than the previous competition sample period with the exception of sample periods 7-12 and 25-30.

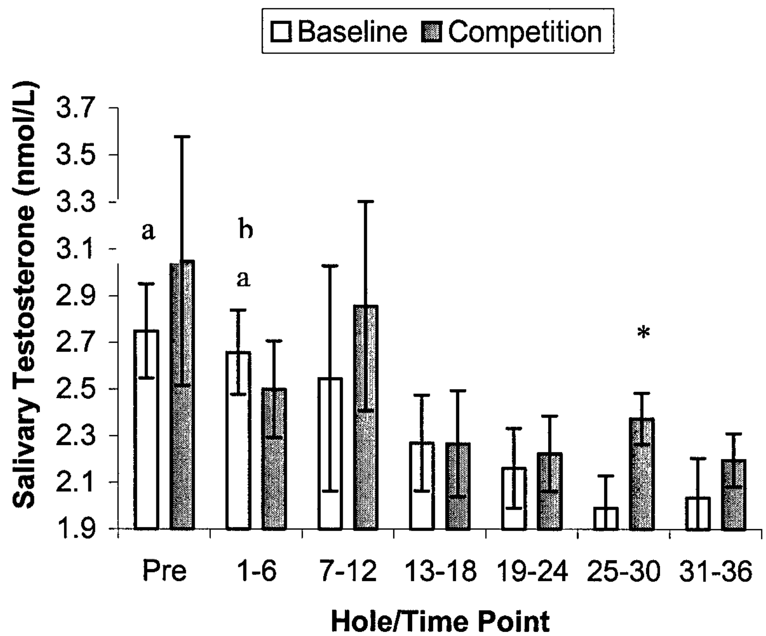


Figure 4.5: Salivary testosterone area under the curve (AUC) measures for baseline and competition. Values are means (± S.E.)
*Significant difference observed between baseline and competition conditions.
(a) Baseline salivary testosterone was significantly higher than sample periods 19-24, 25-30, and 31-36 baseline salivary testosterone.
(b) Significantly higher than baseline 13-18 sample period salivary testosterone

No statistical analysis was performed on individual sample period or hole samples. However the mean and standard error salivary cortisol values for each sample period are presented in figure 4.6. Figures exhibit a normal, circadian pattern [84].

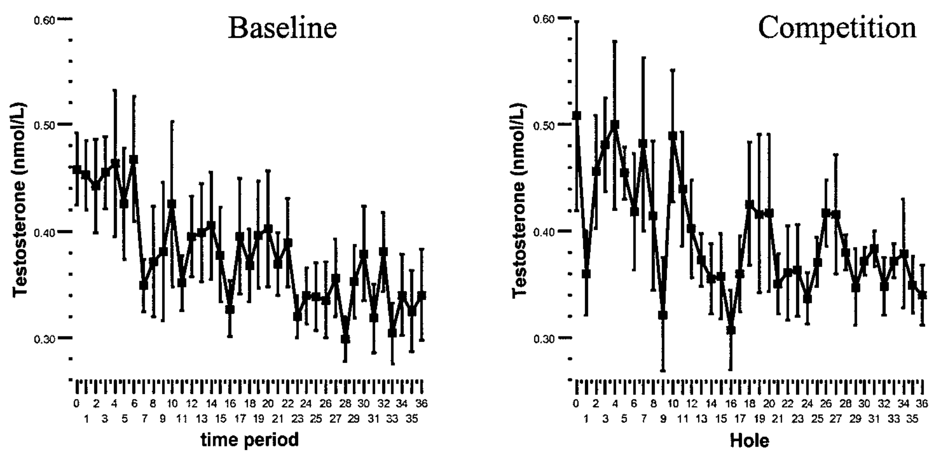


Figure 4.6: Salivary testosterone measures for baseline and competition. Values are means (± S.E.).

Salivary T/C Ratio

Significant competition vs. baseline effect ($F(1,7) = 41.545$, $p < 0.001$) and a significant hole or time point effect ($F(6, 42) = 9.85$, $p < 0.01$) was noted from the ANOVA. No significant interaction was noted between baseline or competition T/C ratio and time of day or hole.

Significant pairwise differences were noted between baseline and competition salivary T/C ratio at all sample periods (Figure 4.7). T/C ratio for the baseline sample period pre was significantly lower than all other sample periods. T/C ratio for baseline sample period 1-6 was significantly lower than baseline sample period 19-24. T/C ratio for competition sample period pre was significantly lower than competition sample periods 7-12 and 13-18. T/C ratio for competition sample period 31-36 was significantly higher than competition sample periods 1-6 and 25-30.

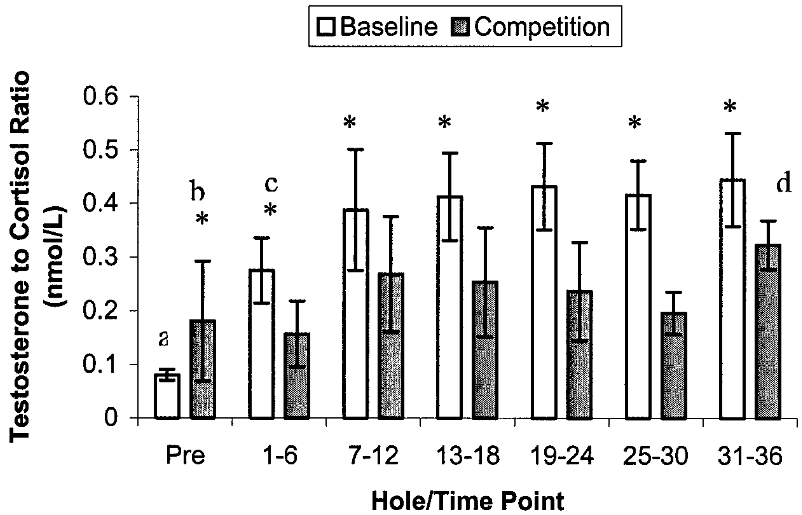


Figure 4.7: T/C ratio AUC measures for a baseline and competition. Values are means (± S.E.).
* A significant ($p < .05$) difference was observed between baseline and competition conditions. (a) Baseline T/C ratio was significantly lower than all subsequent baseline sampling periods. (b) T/C ratio for competition sample period pre was significantly lower than competition sample periods 7-12 and 13-18. (c) Baseline T/C ratio significantly lower than baseline sampling period 19-24. (d) T/C ratio for competition sample period 31-36 significantly higher than competition sample periods 1-6 and 25-30.

No statistical analysis was performed on individual sample period or hole samples. However the mean and standard error salivary cortisol values for each sample period are presented in figure 4.8.

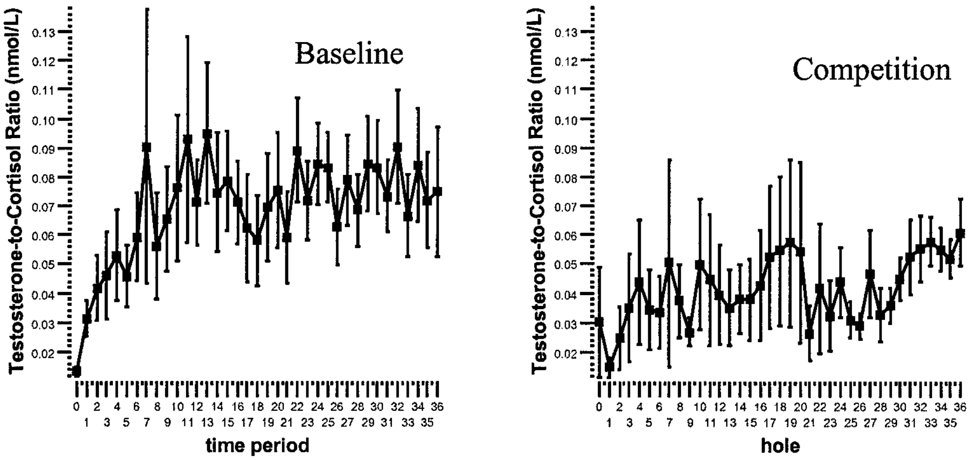


Figure 4.8: Salivary T/C ratio measures for baseline and competition. Values are means (± S.E.).

Perceived Physical Fatigue

There was no significant competition vs. baseline perceived physical fatigue effect. However, there was a significant effect ($F(1,5) = 16.57$, $p < 0.001$) of physical fatigue by hole/time period. However, A significant interaction ($F(1,5) = 7.605$, $p < 0.001$) was noted between baseline and competition perceived physical fatigue condition and time of day or hole.

Significant pairwise differences were observed between baseline and competition perceived physical fatigue only at sample periods 25-30 and 31-36 (Figure 4.9). There were no significant pairwise differences between any baseline perceived fatigue time periods. For competition perceived physical fatigue measures, all sample periods were significantly higher (lower numerically) than all previous competition perceived physical fatigue time periods.

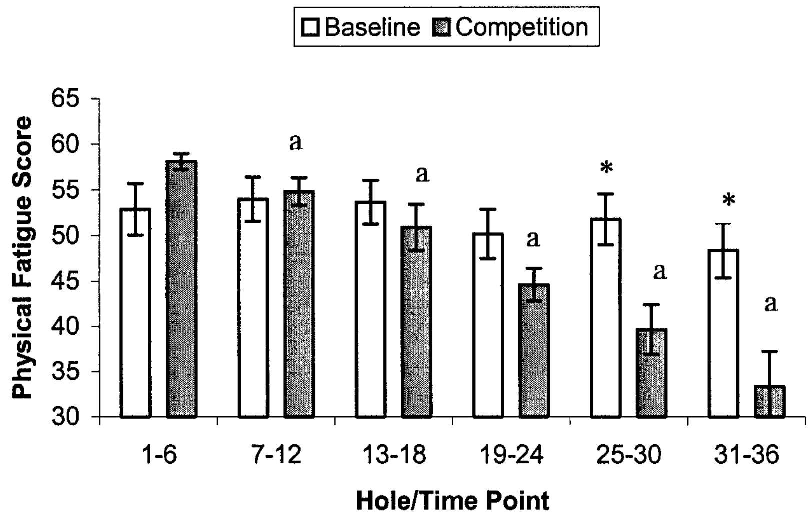


Figure 4.9: Physical fatigue AUC measures for baseline and competition. A lower score indicates a greater level of perceived fatigue. Values are means (± S.E.) * A significant ($p < 0.05$) difference was observed between baseline and competition conditions. (a) Significantly lower than all previous competition time periods.

Perceived Mental Fatigue

There was no significant competition vs. baseline perceived mental fatigue effect. However, there was a significant effect ($F(1,5) = 6.91$, $p < 0.001$) of mental fatigue by hole/time period. No significant interaction was noted between baseline or competition perceived mental fatigue measures and time of day or hole.

Significant pairwise differences were noted between baseline and competition perceived mental fatigue only at sample period 31-36 (Figure 4.10). There were no significant pairwise differences between any baseline perceived mental fatigue time periods. For competition perceived mental fatigue measures, sample periods 25-30 and 31-36 were significantly higher (lower numerically) than all previous competition perceived mental fatigue time periods. Competition perceived mental fatigue sample period 19-24 was significantly greater (lower numerically) than competition sample periods 1-6 and 7-12. Competition perceived mental fatigue sample period 13-18 was significantly greater (lower numerically) than competition sample period 1-6.

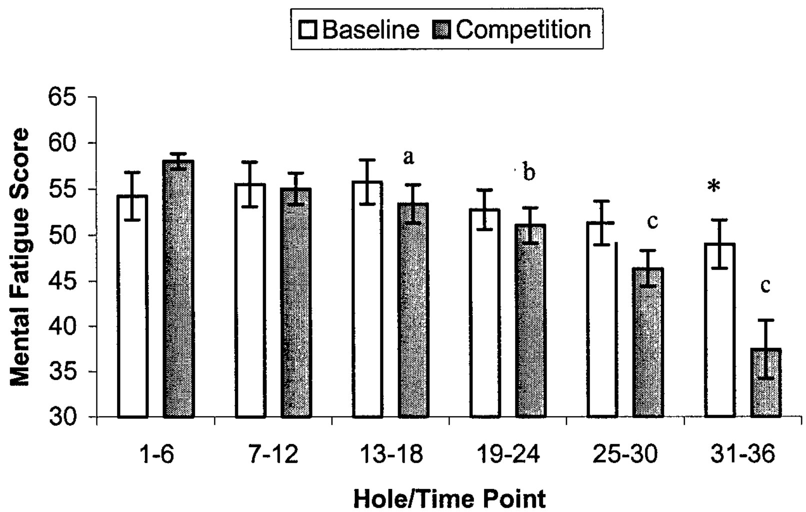


Figure 4.10: Mental fatigue AUC measures for a baseline and competition. A lower score indicates a greater level of perceived fatigue. Values are means (± S.E.). * A significant ($p < 0.05$) difference was observed between baseline and competition conditions. (a) Significantly lower than competition sample periods 1-6. (b) Significantly lower than competition sample periods 1-6 and 7-12. (c) Significantly lower than all previous competition time periods.

Correlations Among Measures

Correlations During Competition

Pearson Product Moment Correlation Coefficients were computed to examine the relationship between 36-hole AUC biochemical measures and normalized 36-hole performance. For cortisol, testosterone, and T/C ratio, differences between competition and baseline measures were summed across all 36 samples to compute one 36-hole AUC value for each biochemical measure per subject. Thirty six-hole AUC T/C ratio difference was significantly ($p < 0.05$) correlated with 36-hole golf score ($r = 0.82$). Lower 36-hole AUC T/C ratio difference measures were associated with lower 36-hole golf scores (Figure 4.11). There was a trend towards a positive correlation between 36-hole AUC testosterone ($r = 0.68$, $p = 0.06$) difference and 36-hole score and a negative correlation between 36-hole AUC cortisol difference and 36-hole score ($r = -0.41$, $p = 0.31$); however, correlations were not significant.

Table 4.1: Pearson product moment correlations between 36-hole AUC biochemical measure responses, perceived fatigue, and 36-hole performance

	36-Hole performance	Mental Fatigue Difference	Physical Fatigue Difference	T/C ratio Difference	Testosterone Difference
Cortisol Difference	-0.41	-0.65	-0.68	-0.51	0.03
Testosterone Difference	0.68	-0.38	-0.21	0.63	
T/C ratio Difference	0.82*	0.20	-0.51		
Physical Fatigue Difference	-0.11	0.70			
Mental Fatigue Difference	-0.23				

* Correlation is significant at the $p < 0.05$ level (2-tailed).
T/C ratio difference = difference between competition and baseline 36 AUC T/C ratio
Cortisol difference = difference between competition and baseline 36 AUC cortisol
Testosterone Difference = difference between competition and baseline 36 AUC testosterone

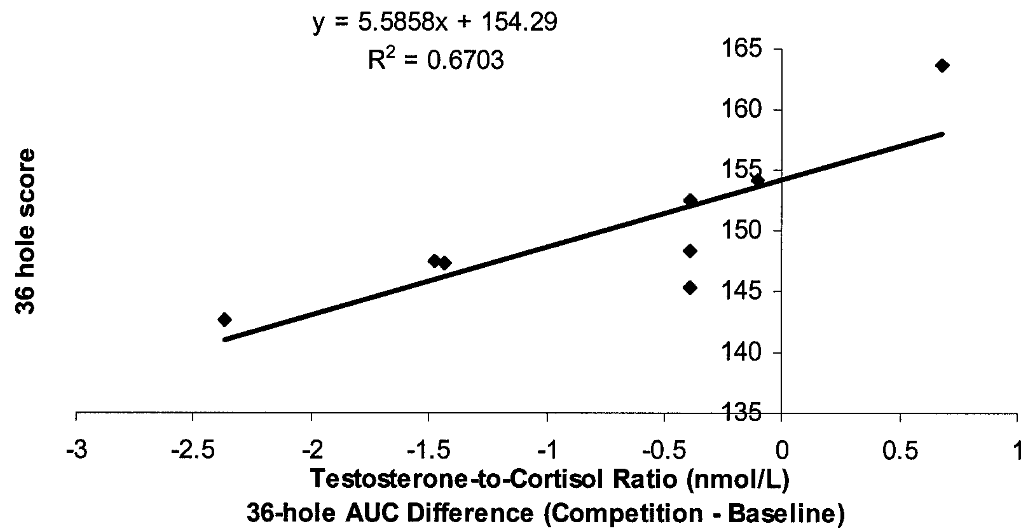


Figure 4.11: Net 36-hole score plotted against 36-hole AUC T/C ratio difference (competition minus baseline).

Pre-round Correlations

Pearson Product Moment Correlation Coefficients were also computed to examine the relationship between pre-round biochemical measures, CSAI-2 components, and 36-hole performance (Table 4.2). Pre-round cortisol difference was significantly positively correlated to CSAI-2 Somatic Anxiety ($r = 0.81$, $p < 0.05$) (Figure 4.12). Pre-round testosterone difference was significantly negatively correlated to CSAI-2 Somatic Anxiety ($r = -0.80$, $p < 0.05$) and significantly positively correlated to 36-hole performance ($r = 0.71$, $p < 0.05$). Additionally, pre-round cortisol difference was negatively correlated ($r = -.81$, $p < .05$) to pre-round testosterone difference. Competition T/C ratio difference was negatively correlated to CSAI-2 Somatic Anxiety ($r = -0.72$, $p < 0.05$) and positively correlated to 36-hole performance ($r = 0.82$, $p < 0.05$). A lower performance score meant a better golf performance, so higher pre-round T/C ratio difference and testosterone difference measures were related to worse golf performance.

Table 4.2: Pearson product moment correlations between pre-round biochemical measures, CSAI-2 components, and 36-hole performance

	36-Hole performance	CSAI-2	Self Confidence	Cognitive Anxiety	Somatic Anxiety	T/C Ratio Difference	Testosterone Difference
ΔCortisol	-0.36	0.39	-0.57	-0.10	0.81*	-0.78*	-0.81*
ΔTestosterone	0.71*	-0.45	0.16	0.32	-0.80*	0.94*	
T/C Ratio Difference	0.82*	-0.36	0.11	0.39	-0.72*		
Somatic Anxiety	-0.51	0.75*	-0.31	0.02			
Cognitive Anxiety	0.61	0.51	-0.18				
Self Confidence	-0.15	0.09					
CSAI-2	-0.17						

*Correlation is significant at the $p < 0.05$ level (2-tailed)
T/C ratio difference = difference between competition and baseline 36 AUC T/C ratio
Cortisol difference = difference between competition and baseline 36 AUC cortisol
Testosterone Difference = difference between competition and baseline 36 AUC testosterone

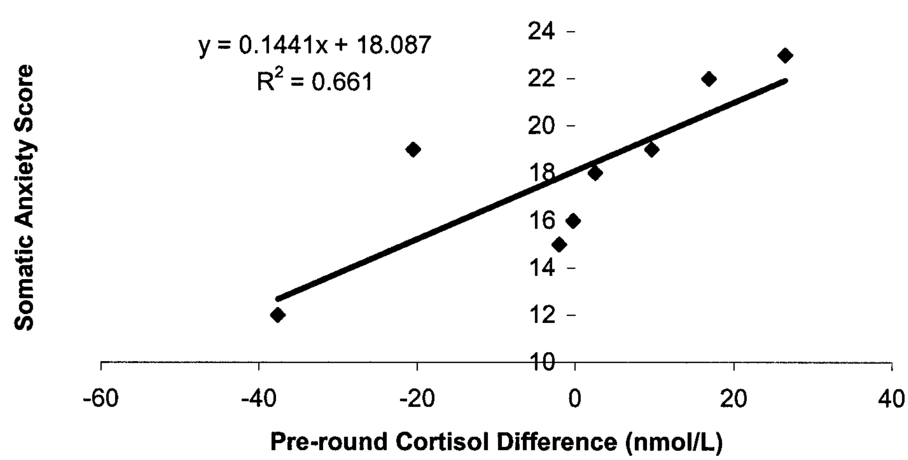


Figure 4.12: Pre-round CSAI-2 Somatic Anxiety Score plotted against pre-round cortisol difference (competition minus baseline).

Pearson product moment correlation coefficients were also computed to examine the relationship between biochemical measures, individual hole and 6-hole AUC performance. There were no significant correlations between performance and testosterone or cortisol measures.

Discussion

This investigation is pioneer, no known previous investigations have studied the sum of testosterone or cortisol responses during an extended sport competition. Most investigations have reported pre- and post-endocrine measurements and related them to following or preceding performance. Additionally, the testosterone response during competitive golf has not been investigated.

Several notable findings resulted from this investigation. The primary finding was significant elevation in salivary cortisol in competitive golf compared to a baseline condition and no significant change in salivary testosterone from the baseline to competitive golf condition. This resulted in a significant decrease in T/C ratio throughout the competition. A high positive correlation ($r = 0.82$, $p < 0.05$) between 36-hole AUC T/C ratio and 36-hole score was noted. Additionally, there was a high positive correlation between pre-round testosterone ($r = 0.82$, $p < 0.05$), T/C ratio ($r = 0.71$, $p < 0.05$) response and 36-hole score. Lastly, there was a strong positive correlation between CSAI-2 somatic anxiety and pre-round cortisol response (0.81, $p < 0.05$) and a strong negative correlation between pre-round testosterone (-0.80, $p < 0.05$) and T/C ratio (-0.72, $p < 0.05$) and CSAI-2 somatic anxiety.

Salivary steroid values of subjects in this investigation are similar to previously reported values. Baseline salivary testosterone values in this investigation averaged across subjects and sample periods (0.38 nmol/L) are comparable to values reported for 100 male college students (0.34 nmol/L) [32]. Early morning (38.6 nmol/L) and evening (6.1 nmol/L) baseline salivary cortisol values in this investigation averaged across subjects are comparable to previously reported early morning (25.5 nmol/L) and evening (6.1 nmol/L) baseline salivary cortisol values reported for 100 male college students [182].

Salivary Cortisol and Testosterone Response During Competition

Salivary cortisol measures during 36-holes of competitive golf (19.0 nmol/L) were significantly elevated an average of 111% from baseline (9.0 nmol/L) salivary cortisol measures. McKay and colleagues reported a similar elevation in cortisol response during competitive golf [126]. Results from this investigation confirm the finding that competitive golf is a significant activator of the HPAA. Elevations in cortisol serum concentration have been noted in anticipation of, or response to, psychological stressors [6, 84, 115] or physical exertion of 70% of $\dot{V}O_2max$ or higher [35, 114]. Investigators report golf to require physical exertion of only 43% to 55% of $\dot{V}O_2max$ [111]. Therefore any elevation in cortisol during golf performance may be presumed to be the result of psychological or competitive stress. Further evidence for this conclusion is that there was no difference between baseline and competition salivary cortisol measures over the final six holes when physical and mental fatigue were the greatest.

Testosterone was elevated in competitive golf (0.42 nmol/L) vs. baseline (0.39 nmol/L). However differences were not statistically significant except when comparing pairwise between competition (0.40 nmol/L) and corresponding baseline (0.33 nmol/L) AUC testosterone values for holes 25-30. This increase in testosterone late in the round may have been due to a reduction in stress (cortisol). Decreasing cortisol may have reduced inhibition of testosterone production [166]. Investigators have noted increases in testosterone from baseline measures to post-athletic competition in wrestling, pistol-shooting, and judo competition [38, 52, 97, 169], while others have reported no change from pre to post-wrestling or judo competition [42, 49, 143, 144]. Interestingly, all investigations reporting rises in testosterone from pre- to post-competition measured serum testosterone, while those reporting no change measured salivary testosterone. This may reflect differences between biocompartments and should be studied further.

Pre-competition Salivary Cortisol and Testosterone Response

Contrary to hypothesis, pre-round cortisol measures were not significantly elevated from the baseline to competitive golf condition. These results agree with only one previous investigation with basketball players [49]. However, most previous investigators have reported anticipatory cortisol rises prior to competition in tennis players [14], marathon runners [28, 59], pistol shooters [52], weight lifters [143], and judo fighters [42, 169]. A possible explanation for this disparity in results is the early

(7:15 A.M.) pre-round sampling time used in this investigation, the long time period before competition (45 minutes), or the presence of an unknown stressor in the corresponding baseline sample. Researches have linked the daily cortisol secretion pattern to awakening time and report peak secretions at 30 minutes after wake up [37]. Although sample times were identical, subject's wake-up time was not controlled and they may have awakened earlier on the competitive day, thus providing for a longer wakeful time prior to sampling, possibly reducing the first competition-day cortisol sample. A very high first baseline sample (38.6 nmol/L) was observed compared to the next baseline sample (15.7 nmol/L) (Figure 4.3). A more expected comparison ($p < 0.05$) results when comparing first-hole competition sample mean (32.9 nmol/L) to the corresponding baseline sample mean (15.7 nmol/L). A similar result was reported in marathon runners. One hour prior to the race, competition and baseline cortisol were not different. However, immediately prior to the race, salivary cortisol was significantly elevated compared to time-matched baseline cortisol [28].

Golfers in this investigation did not exhibit a significant anticipatory rise in salivary testosterone. Similarly, testosterone did not rise prior to wrestling [97, 144], judo competition [42], or skydiving [21]. However, several previous investigators noted anticipatory testosterone rises prior to competition in tennis players [14], marathon runners [28], pistol shooters [52], and judo fighters [169]. Additionally, anticipatory rises were reported during a chess competition only in winners [119]. Loser's testosterone did not rise prior to the match. The rationale for this disparity in results is unknown.

There may be some specific reasons for the failure of testosterone to rise in anticipation of competition in this investigation. Possibly sample time was too long before the competition (45 minutes) or golf requires a different mood state since there is not a direct opponent or face-to-face competition in golf. Most of the previous findings of an anticipatory rise in testosterone were during face-to-face competition. A sport like golf where an individual is competing for a score against an entire field of opponents may elicit a different hormonal response.

Salivary T/C Ratio

T/C ratio is a good indicator of anabolic to catabolic hormone status and investigators have suggested T/C ratio as a marker of overtraining. Plasma values below 0.35 10^{-3} or a decrease of the T/C ratio of 30% or more could be an indication of overtraining [1, 9]. Although T/C ratio has been developed and used as a marker for overtraining following exhaustive physical training, it may be valuable as an indicator of overstrain during psychopysiological stress. Authors recommend limiting of high intensity exercise and competition to avoid overtraining syndrome [177]. Salivary T/C ratio values for individual subjects in this investigation ranged from 0.60 X 10^{-3} nmol/L to 0.23 nmol/L in competition. However, for almost 10 hours of the day, golfers' T/C ratios in competition (0.026 nmol/L) were an average of 45% below baseline T/C ratio values (0.048 nmol/L), which indicates a high level of hormonal strain. Passelergue and colleagues (1995) also reported a low T/C ratio during wrestling competition [143].

In a recent review article, authors suggested endurance overtraining and chronic psychological stress to have similar effects [23]. Authors warned the synergistic effects psychological and physiological stress might have detrimental effects on the immune system. Further research is required to assess the effects of this prolonged hormonal strain on fatigue, recovery, subsequent performance, immune function, and long-term health.

Mental and Physical Fatigue

The golfers' perceived physical and mental fatigue exhibited a similar pattern in this investigation. The only pairwise differences that occurred between baseline and competitive golf conditions were at holes 25-30 and 31-36 for physical fatigue and holes 31-36 for mental fatigue. There were no differences by time of day in perceived mental or physical fatigue throughout the baseline day. However, the ANOVA showed a significant interaction between competitive condition and time of sample. Perceived physical and mental fatigue during the competitive golf day exhibit a declining (increasing fatigue) pattern over the last four sample periods. It appears 36 holes of competitive golf, while carrying clubs, is perceived to be more physically and mentally fatiguing than normal daily activities, particularly near the end of the round. The main purpose of including the perceived fatigue measures in this investigation was to relate perceived mental and physical fatigue to endocrine measures and performance; however, there were no significant relationships. Kraemer and colleagues also reported no correlation between mental or physical fatigue and cortisol response [95].

Correlations Among Measures

Correlations During Competition

Unlike previous investigations, this competition was not over, so clear winners and losers could not be identified. Data was collected during the first 36-holes of the competition only. The players had one more 18-hole round the following day to complete the competition. There were no winners or losers after the first two rounds, however individuals appraised their own performance relative to past performances and the rest of the competitive field and relative performance could be related to endocrine and perceived anxiety measures.

It is not surprising that testosterone, cortisol, and T/C ratio were not significantly correlated with performance by hole or 6-hole AUC given the day-to-day variation in hormone responses, the complex nature of golf performance, and delayed action from stimulus to salivary hormone appearance. One investigation reported a 20 minute time delay from LH spike to peak rise in blood testosterone secretion [180]. Salivary cortisol concentration peaks 30 to 45 minutes after stimulus and remained elevated for 60 to 90 minutes [76, 84]. Therefore summing the hormone responses across all 36 holes and associating totals to final performance may provide more meaningful results.

Although correlations were not statistically significant, 36-hole performance was negatively associated with cortisol response ($r = -0.51$) and positively associated with testosterone response ($r = 0.63$) response during the competition. The correlation between T/C ratio and 36-hole performance, however, was high and significant ($r = 0.82$, $p < 0.05$). Correlations between raw golf scores and endocrine measures were near identical to these correlations with the normalized golf scores. This is further evidence of the homogeneity of these subjects' golf ability.

Previous investigators have compared post-competition cortisol responses in winners and losers. Greater increases in cortisol from pre to post-competition have been noted in winners vs. losers [14, 38, 143, 169]. Passelergue and colleagues (1995) also reported a low T/C ratio during competition, significantly lower T/C ratios in winners vs. losers, and a significant positive correlation between pre-competition cortisol response and performance [143]. The mechanism for this relationship is unknown, however better performers might be more concerned (stressed) about their performance while worse performers may have relaxed or "given up".

Pre-round Correlations

Pre-round cortisol response (competition minus baseline) was highly correlated ($r = 0.81$, $p < .05$) to the somatic anxiety measure of the CSAI-2. Few studies have validated the CSAI-2 with physiological measures of anxiety. Yan Lan and Gill (1984) reported no relationship between heart rate and CSAI-2 components [203], while McKay (1997) reported no relationship between somatic anxiety and cortisol response to competitive golf [126]. However, Filaire and colleagues reported significant correlations between somatic state anxiety, cognitive state anxiety and cortisol [42]. Similarly, other investigators have reported significant correlations between cortisol response and more general anxiety measures [59, 178].

Pre-round testosterone response had a high negative correlation ($r = -0.80$, $p < 0.05$) with somatic anxiety. This relationship has not been previously investigated, but is not surprising since glucocorticoids act directly at the testicle to inhibit responsiveness to luteinizing hormone [166] and chronic stress may cause reductions in testosterone production [100]. Additionally, investigators have correlated low testosterone with psychosocial stress [45, 139].

Pre-round testosterone response was also highly negatively correlated ($r = -0.71$, $p < 0.05$) to 36-hole performance. This relationship has not been previously reported, however, when Gonzalez-Bono (1999) analyzed participants by outcome, winners had slightly suppressed pre-competition testosterone, while losers showed significant anticipatory rises in testosterone [49].

Conclusion

36-holes of competitive golf exposed the body to almost 10 hours of hormonal stress. Cortisol is elevated and testosterone-to-cortisol ratio is decreased for most of the competitive round. The effects on health and subsequent performance are unknown.

Results also indicated a significant positive correlation of 36-hole golf score with pre-round testosterone and the 36-hole AUC T/C ratio response. Mechanisms for this relationship are unclear. High testosterone and aggressive, dominating moods may not be facilitative to golf performance, and better performers may be more stressed or concerned about their performance, reducing T/C ratio throughout the round.

Chapter 5

Summary, Conclusions, and Recommendations for Future Research

Study #1: The Effects of Strength, Power, and Flexibility Training on Golf Performance in Competitive Intercollegiate Men and Women Golfers

Summary

Several investigations have reported increases in clubhead speed or driving distance following physical conditioning in recreational male golfers. However, the effect of physical conditioning on golf performance in elite-level men and women players is unclear from the literature. The purpose of this investigation was to determine the effects of a physical conditioning program (strength, power and flexibility training) on club head speed, consistency, and putting distance control in elite college-level men and women golfers.

Subjects were ten men and six women NCAA Division I golfers. Supervised strength, power, and flexibility training was performed 3 times per week for 11 weeks. Golf ball launch conditions, putting distance control, strength, power, and flexibility tests were conducted before and after training.

Hypotheses

Following strength, power and flexibility training:

1. Strength, trunk power, and trunk flexibility will increase.
   - Finding: Significant ($p < 0.05$) increases were noted for all strength,

power, and flexibility tests from pre to post training: grip strength (7.3%); bench press (10.2%); lat pull (12.6%); squat (13.3%); and shoulder press (23.6%); rotational power (19.9%); and trunk rotation flexibility (12.3%).

2. Swing mechanics will not change.
   - No consistent trends were noted. Concluded changes in clubhead speed were due to increased muscle power supplied by the golfer, not changes in mechanics.
3. Clubhead speed will increase.
   - Finding: Mean clubhead speed for the intercollegiate men and women golfers increased (1.6%) significantly ($p < 0.05$) from 47.3 to 48.0 m/s equating to approximately a 4.9-meter increase in driving distance. This increase in clubhead speed is lower than previously reported increases in clubhead speed or distance of 4 to 7% in predominantly recreational male golfers following resistance and flexibility training [64, 74, 103, 106, 168, 190, 193, 194].
4. Consistency will improve.
   - Finding: No significant differences were observed between pre- and post-training values for clubface-angle or launch-angle deviation.
5. Putting distance control will improve following strength, power and flexibility training.
   - Finding: Putting distance control significantly ($p < 0.05$) improved from pre to post-training for the men-only group (29.6%), while there was no significant difference in putting distance control for the total and women-

only groups

6. Strength, trunk power, and trunk flexibility measures will be positively correlated to clubhead speed.
    - Pearson r correlation analysis resulted in only one significant ($p < 0.05$) correlation between clubhead speed and rotational power ($r = 0.86$).

Conclusions

Competitive, recreational, and especially collegiate golfers have limitations on practice time. It is valuable to know the effects of different training methods in order 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 an important factor in generating clubhead speed and skilled men and women golfers should engage in weight training, stretching, and rotational power training to improve golf performance.

Recommendations for Future Study

A three-dimensional motion analysis of golfers before and after a strength-training program would provide a more sensitive means for detecting changes in technique due to physical conditioning. Also, a back-swing-side sagittal or down-the-line view would have provided opportunity for qualitative analysis of additional important swing elements such as swing plane and postural changes.

Due to the short duration of the training, most of the gains in strength in this investigation were likely due to neural adaptations [160]. A longer training period may cause increases in muscle size and strength, which may have different effects on swing mechanics, clubhead speed, and putting distance control.

The short time period available for training did not allow for a fully periodized training program. The athletes were not able to train at lower repetition maximum loads (1 to 7 RM) more optimal for strength and power development. The strength coach did not feel the athletes had an adequate strength-training base to progress to these higher intensities in the first 8 weeks of training. Ideally, more time in training would allow a longer linear or non-linear periodized training program that might elicit greater strength and power gains and greater performance gains. Additionally, it would be valuable to investigate the effects of an in-season resistance-training program on performance. However, the rigorous competition, travel, and academic schedule of subjects participating in this study would not allow continuation of the training into the competitive season.

Previous studies using baseball batting and pitching have documented greater increases in performance when rotational medicine ball throws were performed in addition to traditionally resistance training. A similar study with golfers would produce valuable information for developing golf-specific training programs.

Study #2:Salivary Cortisol, Testosterone, and T/C Ratio Responses During a 36-hole Golf Competition

Summary

The purpose of this investigation was to study the effects of 36 continuous holes of competitive golf on salivary testosterone, cortisol, and testosterone-to-cortisol ratio and their relation to performance in elite male competitive collegiate golfers. Subjects were eight NCAA Division I men golfers. Saliva samples were taken 45 minutes prior to the round and after each hole during a 36-hole competition. Time matched baseline samples were collected to account for circadian rhythm. The Competitive State Anxiety Inventory-2 (CSAI-2) was used to measure pre-round self-reported state anxiety.

Hypotheses

1. Salivary cortisol will be higher in golf tournament competition than a baseline condition.
   - Salivary cortisol measures during 36-holes of competitive golf (19.0 nmol/L) were significantly ($p < 0.05$) elevated an average of 111% from baseline (9.0 nmol/L) salivary cortisol measures.
2. Salivary testosterone will not change in golf tournament competition compared to a baseline condition.
   - Testosterone was elevated in competitive golf (0.42 nmol/L) vs. baseline (0.39 nmol/L). However differences were not statistically significant except when

comparing pairwise between competition (0.40 nmol/L) and corresponding baseline (0.33 nmol/L) AUC testosterone values for holes 25-30.

3. T/C ratio will be lower in golf tournament competition than a baseline condition.
   - T/C ratios in competition (0.026) were an average of 45% below baseline T/C ratio values (0.048).
4. Perceived fatigue will be greater during competition than baseline.
   - Greater fatigue later in golf round compared to baseline.
5. Salivary cortisol will be negatively correlated to performance.
   - No significant correlation was noted between salivary cortisol and golf performance.
6. Salivary T/C ratio will be positively correlated to performance.
   - A high positive correlation ($r = 0.82$, $p < 0.05$) between 36-hole T/C ratio and 36-hole score was noted.
7. Pre-round salivary cortisol will be positively correlated to pre-competition somatic anxiety as measured by the CSAI-2.
   - There was a strong positive correlation between CSAI-2 somatic anxiety ($r = .81$, $p < 0.05$) and pre-round cortisol response
8. Pre-round salivary testosterone will be elevated in competition compared to baseline.
   - Pre-round salivary testosterone did not change from baseline to competition
9. Pre-round salivary cortisol will be elevated in competition compared to baseline
   - Pre-round salivary cortisol did not change from baseline to competition

Conclusion

36-holes of competitive golf exposed the body to almost 10 hours of hormonal stress. Cortisol is elevated and testosterone-to-cortisol ratio is decreased for most of the competitive round. The effects on health and subsequent performance are unknown.

Results also indicated a significant positive correlation of 36-hole golf score with pre-round testosterone and the 36-hole AUC T/C ratio response. Mechanisms for this relationship are unclear. High testosterone and aggressive, dominating moods may not be facilitative to golf performance, and better performers may be more stressed or concerned about their performance, reducing T/C ratio throughout the round.

Recommendations for Future Study

Tracking physiological measures of stress, fatigue, and performance over the days and hours following 36 holes of competitive golf may produce valuable information for golfers. A similar study was done with wrestlers and testosterone and T/C ratio were elevated for five days following the competition. Also, subjects reported high levels of perceived fatigue [144].

Blood glucose levels throughout 36-holes of golf competition may provide valuable information for nutrient intake during competitive golf. Finger sticks might be a feasible way to measure this in future investigations.

The alarm reaction to a stressor or sympathetic nervous system activity was not investigated and obviously plays a role in golf performance. Salivary amylase levels are indication of sympathetic nervous system activity [21] and could be studied similarly to testosterone and cortisol in this investigation.

Repeating this investigation during the final round of a competition may produce different results. Final round psychological stress may be lower or higher depending on the standing of the individual and team in the competition. Additionally, more clear winners and losers may allow for a better comparison with post-round endocrine response.

A combination of the two studies presented in this dissertation may also be a valuable avenue for future research. Resistance and endurance training may have an effect on endocrine stress response, possibly causing stress-response alterations during competitive golf. Kraemer and colleagues (1999) demonstrated that chronic resistance training reduces resting cortisol levels in older men, without an increase in ACTH concentration [94]. Reduced hormonal response to stressors has also been noted in elite endurance athletes versus sedentary controls [130].

References

1. ADLERCREUTZ, H., M. HARKONEN, K. KUOPPASALMI, H. NAVERI, I. HUHTANIEMI, H. TIKKANEN, K. REMES, A. DESSYPRIS, and J. KARVONEN. Effect of training on plasma anabolic and catabolic steroid hormones and their response during physical exercise. *Int J Sports Med.* 7 Suppl 1:27-28., 1986.
2. ADLINGTON, G. S. Proper swing technique and biomechanics of golf. *Clinics in sports medicine.* 15:9-26, 1996.
3. ALMON, R. R. and D. C. DUBOIS. Fiber-type discrimination in disuse and glucocorticoid-induced atrophy. *Med Sci Sports Exerc.* 22:304-311., 1990.
4. ALPENFELS, E. Common pre-swing and in-swing tendencies of amateur golfers. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* A. J. Cochran and M. R. Farrally (Eds.) London: E & FN Spon, 1994, pp. 103-108.
5. 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.
6. ARTHUR, A. Z. Stress as a state of anticipatory vigilance. *Percept Mot Skills.* 64:75-85., 1987.
7. BABINEAU, J. E. Golfweek website, www.golfweek.com, Golfweek Collegiate Golf Rankings. Available at: www.golfweek.com Accessed, 2001.
8. BAECHLE, T. R. and R. W. EARLE (Eds.). *Essentials of Strength Training and Conditioning*. Champaign, IL: Human Kinetics, 2000.
9. BANFI, G., M. MARINELLI, G. S. ROI, and V. AGAPE. Usefulness of free testosterone/cortisol ratio during a season of elite speed skating athletes. *Int J Sports Med.* 14:373-379., 1993.
10. BARRENTINE, S. W., G. S. FLEISIG, H. JOHNSON, and T. W. WOOLLEY. Ground reaction forces and torques of professional and amateur golfers. 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. 33-39.
11. BATT, M. E. A survey of golf injuries in amateur golfers. *Br J Sports Med.* 26:63-65., 1992.

12. BATUMAN, O. A., D. SAJEWSKI, J. E. OTTENWELLER, D. L. PITMAN, and B. H. NATELSON. Effects of repeated stress on T cell numbers and function in rats. *Brain Behav Immun*. 4:105-117., 1990.

13. BECHLER, J. R., F. W. JOBE, M. PINK, J. PERRY, and P. A. RUWE. Electromyographic analysis of the hip and knee during the golf swing. *Clin J Sport Med*. 5:162-166., 1995.

14. BOOTH, A., G. SHELLEY, A. MAZUR, G. THARP, and R. KITTOK. Testosterone, and winning and losing in human competition. *Horm Behav*. 23:556-571., 1989.

15. BOYLE, N. Immunoregulation of Interleukin-1 and Interactions with Plasma Corticosteroids. In: *Stress Effects on Central and Peripheral Systems: A Primer*. P. H. Pfister (Ed.) Brisbane, Australia: Australian Academic Press, 1992.

16. 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.

17. BURTON, D. Do anxious swimmers swim slower? Reexamining the elusive anxiety performance relationship. *The journal of sport and exercise psychology USA*. 10:45-61, 1988.

18. CATTELL, R. B. and I. H. SCHEIER. Stimuli related to stress, neuroticism, excitation, and anxiety response patterns: Illustrating a new multivariate experimental design. *Journal of Abnormal and Social Psychology*. 60:195-204, 1960.

19. CHAO, E. Y., W. P. COONEY, T. D. CAHALAN, and K. TAMAI. Biomechanics of golf swing and a comparison of club handle design. *Biomedical sciences instrumentation*. 23:23-27, 1987.

20. CHAPMAN, C., A. M. LANE, J. H. BRIERLEY, and P. C. TERRY. Anxiety, self-confidence and performance in Tae Kwon-Do. *Percept Mot Skills*. 85:1275-1278., 1997.

21. CHATTERTON, R. T., JR., K. M. VOGELSONG, Y. C. LU, and G. A. HUDGENS. Hormonal responses to psychological stress in men preparing for skydiving. *J Clin Endocrinol Metab*. 82:2503-2509., 1997.

22. CHEETHAM, P. J., P. E. MARTIN, R. E. MOTTRAM, and B. F. ST.--LAURENT. *The importance of stretching the X factor in the golf downswing - abstract*, 2000

23. CLOW, A. and F. HUCKLEBRIDGE. The impact of psychological stress on immune function in the athletic population. *Exerc Immunol Rev*. 7:5-17, 2001.

24. 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. *Heinemann, London, c1968, xiii*. 242, 1968.

25. COCHRAN, A. J. *Club face flexibility and coefficient of restitution*, 1999

26. 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.

27. COOK, D., B. GANSNEDER, R. ROTELLA, C. MALONE, L. BUNKER, and D. OWENS. Relationship among competitive state anxiety, ability and golf performance. *Journal of Sport Psychology*. 5:460-465, 1983.

28. COOK, N. J., G. F. READ, R. F. WALKER, B. HARRIS, and D. RIAD-FAHMY. Changes in adrenal and testicular activity monitored by salivary sampling in males throughout marathon runs. *Eur J Appl Physiol Occup Physiol.* 55:634-638, 1986.

29. COOPER, M. A. J. and J. S. B. MATHER. Categorization of golf swings. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* M. R. Farrally and A. J. Cochran (Eds.) London: E & FN Spon, 1994, pp. 65-70.

30. CORRIGAN, C. Whippy or stiff - which shafts are better for you? *Golf journal 32(4), Jul 1979, 16 18, Total Pages: 3*, 1979.

31. CUMMING, D. C., M. E. QUIGLEY, and S. S. YEN. Acute suppression of circulating testosterone levels by cortisol in men. *J Clin Endocrinol Metab.* 57:671-673., 1983.

32. DABBS, J. M., JR. Salivary testosterone measurements in behavioral studies. In: *Saliva as a diagnostic fluid.* D. Malamud and L. Tabak (Eds.) New York: New York Academy of Sciences, 1993, pp. 177-183.

33. DABBS, J. M., JR., B. C. CAMPBELL, B. A. GLADUE, A. R. MIDGLEY, M. A. NAVARRO, G. F. READ, E. J. SUSMAN, L. M. SWINKELS, and C. M. WORTHMAN. Reliability of salivary testosterone measurements: a multicenter evaluation. *Clin Chem.* 41:1581-1584., 1995.

34. DAVIDSON, J. D. and T. T.J. Determinants of success among professional golfers. *Research Quarterly.* 57:60-67, 1986.

35. DAVIES, C. T. and J. D. FEW. Effects of exercise on adrenocortical function. *J Appl Physiol.* 35:887-891., 1973.

36. 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 & FN Spon, 1994, pp. 3-13.

37. EDWARDS, S., P. EVANS, F. HUCKLEBRIDGE, and A. CLOW. Association between time of awakening and diurnal cortisol secretory activity. *Psychoneuroendocrinology.* 26:613-622., 2001.

38. ELIAS, M. Serum cortisol, testosterone, and testosterone-binding globulin responses to competitive fighting in human males. *Aggressive Behavior.* 7:215-224, 1981.

39. ENDLER, N. S. Interaction model of anxiety: some possible implications. In: *Psychology of Motor Behaviour and Sport.* D. M. a. C. Landers, R.W (Ed.) Champaign, IL: Human Kinetics, 1977, pp. 332-351.

40. ENGELHARDT, G. M. Differences in shot-making skills among high and low money winners on the PGA tour. *Perceptual and Motor Skills.* 84:1314, 1997.

41. EVANS, P. J., J. R. PETERS, J. DYAS, R. F. WALKER, D. RIAD-FAHMY, and R. HALL. Salivary cortisol levels in true and apparent hypercortisolism. *Clin Endocrinol (Oxf).* 20:709-715., 1984.

42. FILAIRE, E., M. SAGNOL, C. FERRAND, F. MASO, and G. LAC. Psychophysiological stress in judo athletes during competitions. *J Sports Med Phys Fitness.* 41:263-268., 2001.

43. FISHER, L. A. Corticotropin-releasing factor: endocrine and autonomic integration

of responses to stress. *Trends Pharmacol Sci.* 10:189-193., 1989.

44. FLECK, S. J. and W. J. KRAEMER. *Designing Resistance Training Programs.* Champaign, IL: Human Kinetics, 1999
45. FRANCIS, K. T. The relationship between high and low trait psychological stress, serum testosterone, and serum cortisol. *Experientia.* 37:1296-1297., 1981.
46. FRISWELL, M. I., J. E. MOTTERSHEAD, and M. G. SMART. Dynamic models of golf clubs. *Sports engineering.* 1:41-50, 1998.
47. FRY, A. C., W. J. KRAEMER, S. J. FLECK, N. T. TRIPLETT MCBRIDE, L. P. KOZIRIS, and S. E. GORDON. The effects of competitive wrestling success on acute hormonal responses.(Abstract). *Journal of strength and conditioning research.* 15:1, 2001.
48. GARRISON, L. E. Electromyographic - cinematographic study of muscular activity during the golf swing. *Thesis.* Florida State University1963.
49. GONZALEZ-BONO, E., A. SALVADOR, M. A. SERRANO, and J. RICARTE. Testosterone, cortisol, and mood in a sports team competition. *Horm Behav.* 35:55-62., 1999.
50. GOODMAN, H. M. *Basic Medical Endocrinology.* Second ed. New York: Lippincott-Raven Publishers, 1994
51. GOULD, D., L. PETLICHKOFF, J. SIMONS, and M. VEVERA. Relationship between competitive state anxiety inventory-2 and pistol shooting performance. *Journal of Sport Psychology.* 9:33-42, 1987.
52. GUEZENNEC, C. Y., J. P. LAFARGE, V. A. BRICOUT, D. MERINO, and B. SERRURIER. Effect of competition stress on tests used to assess testosterone administration in athletes. *Int J Sports Med.* 16:368-372., 1995.
53. GWYN, R. G. and C. E. PATCH. Comparing two putting styles for putting accuracy. *Perceptual and motor skills.* 76:387-390, 1993.
54. GWYN, R. G., F. ORMOND, and C. E. PATCH. Comparing putters with a conventional blade and a cylindrically shaped clubhead. *Perceptual and motor skills.* 82:31-34, 1996.
55. HACKFORT, D. and C. D. SPIELBERGER. Sport-related anxiety: current trends in theory and research. In: *Anxiety in sports - an international perspective.* D. Hackfort and C. D. Spielberger (Eds.) New York: Hemisphere Publishing, 1989, pp. 261-267.
56. HAKKINEN, 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). *Scandinavian journal of sports sciences FINLANDE.* 7:55-64, 1985a.
57. HAKKINEN, 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. *Scandinavian Journal of Sports Science.* 7:65-76, 1985b.
58. 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.

59. HARRIS, B., N. J. COOK, R. F. WALKER, G. F. READ, and D. RIAD-FAHMY. Salivary steroids and psychometric parameters in male marathon runners. *Br J Sports Med.* 23:89-93., 1989.

60. HAY, J. D. *The Biomechanics of Sports Techniques*. 4th ed. Englewood Cliffs, New Jersey: Prentice Hall, 1993

61. HAY, J. G. *Anatomy, Mechanics and Human Motion*. 2nd ed. Englewood Cliffs, New Jersey: Prentice Hall, 1988

62. HELLHAMMER, D. H., W. HUBERT, and T. SCHURMEYER. Changes in saliva testosterone after psychological stimulation in men. *Psychoneuroendocrinology.* 10:77-81, 1985.

63. HENRY, J. P. Biological basis of the stress response. *Integr Physiol Behav Sci.* 27:66-83., 1992.

64. HETU, F. E., C. A. CHRISTIE, and A. D. FAIGENBAUM. Effects of conditioning on physical fitness and club head speed in mature golfers.:, 1998.

65. HIRAMATSU, R. Direct assay of cortisol in human saliva by solid phase radioimmunoassay and its clinical applications. *Clin Chim Acta.* 117:239-249., 1981.

66. 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.

67. HOSEA, T. M., C. J. GATT, K. M. GALLI, N. A. LANGRANA, and J. P. ZAWADSKY. Biomechanical analysis of the golfer's back. *Science and Golf, Proceedings of the First World Scientific Congress of Golf*:43-48, 1990.

68. HOSEA, T. M. and C. J. GATT, JR. Back pain in golf. *Clin Sports Med.* 15:37-53., 1996.

69. HUNTER, C. L. Sequence of hip and selected upper extremity joint movements during the golf drive. *Univ. of Oregon, Eugene, Ore.* 2, 1973.

70. JOBE, F. W., D. R. MOYNES, and D. J. ANTONELLI. Rotator cuff function during a golf swing. *Am J Sports Med.* 14:388-392., 1986.

71. JOBE, F. W., J. PERRY, and M. PINK. Electromyographic shoulder activity in men and women professional golfers. *Am J Sports Med.* 17:782-787., 1989.

72. JOBE, F. W., L. A. YOCUM, R. E. MOTTRAM, and M. M. PINK. *Exercise guide to better golf.* Inglewood, CA: Champion Press, 1994

73. JOBE, F. W. and M. M. PINK. Shoulder pain in golf. *Clin Sports Med.* 15:55-63., 1996.

74. JONES, D. The Effects of Proprioceptive Neuromuscular Facilitation Flexibility Training on the Clubhead Speed of Recreational Golfers. In *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf.* St Andrews, Scotland: Human Kinetics,, 1998.

75. JORGENSEN, T. On the dynamics of the swing of a golf club. *American Journal of Physics*. 38:644-651, 1970.

76. KAHN, J. P., D. R. RUBINOW, C. L. DAVIS, M. KLING, and R. M. POST. Salivary cortisol: a practical method for evaluation of adrenal function. *Biol Psychiatry.*

23:335-349., 1988.
77. 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. *Scandinavian Journal of Sports Science*. 5:50-55, 1983.
78. KANEKO, Y. and F. SATO. The optimization of golf swing and its application to the golfclub design. In *Abstracts of the Internaltional Society of Biomechanics, XIVth Congress*. Paris:, pp. 652-653, 1993.
79. KANWAR, K. and R. V. CHOWGULE. One move to better ball flight. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* A. J. Cochran and M. R. Farrally (Eds.) London: E & FN Spon, 1994, pp. 97-102.
80. KAO, J. T., M. PINK, F. W. JOBE, and J. PERRY. Electromyographic analysis of the scapular muscles during a golf swing. *Am J Sports Med.* 23:19-23., 1995.
81. KAWASHIMA, K., T. MESHIZUKA, and S. TAKESHITA. A kinematic analysis of foot force exerted on the soles during the golf swing among skilled and unskilled golfers. *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf*, 1998.
82. KHAN-DAWOOD, F. S., J. K. CHOE, and M. Y. DAWOOD. Salivary and plasma bound and "free" testosterone in men and women. *Am J Obstet Gynecol.* 148:441-445., 1984.
83. KHANSARI, D. N., A. J. MURGO, and R. E. FAITH. Effects of stress on the immune system. *Immunol Today.* 11:170-175., 1990.
84. KIRSCHBAUM, C. and D. H. HELLHAMMER. Salivary cortisol in psychobiological research: an overview. *Neuropsychobiology.* 22:150-169, 1989.
85. KNUTTGEN, H. G. and W. J. KRAEMER. Terminology and Measurement in Exercise Performance. *Journal of Applied Sport Science Research.* 1:1-10, 1987.
86. KOENIG, G., M. TAMRES, and R. W. MANN. An analysis of the kinetics and kinematics of the golf swing. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* M. R. Farrally and A. J. Cochran (Eds.) London: E & FN Spon, 1994, pp. 40-45.
87. KOHLMAIER, J. T. Coordination in golf swing: advanced vs. novice golfers.:, 1998.
88. KRAEMER, W. J., L. MARCHITELLI, S. E. GORDON, E. HARMAN, J. E. DZIADOS, R. MELLO, P. FRYKMAN, D. MCCURRY, and S. J. FLECK. Hormonal and growth factor responses to heavy resistance exercise protocols. *J Appl Physiol.* 69:1442-1450., 1990.
89. KRAEMER, W. J., S. E. GORDON, S. J. FLECK, L. J. MARCHITELLI, R. MELLO, J. E. DZIADOS, K. FRIEDL, E. HARMAN, C. MARESH, and A. C. FRY. Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *Int J Sports Med.* 12:228-235., 1991.
90. KRAEMER, W. J., A. C. FRY, B. J. WARREN, M. H. STONE, S. J. FLECK, J. T. KEARNEY, B. P. CONROY, C. M. MARESH, C. A. WESEMAN, N. T. TRIPLETT, and ET AL. Acute hormonal responses in elite junior weightlifters. *Int J Sports Med.* 13:103-109., 1992.
91. 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. KNUTTGEN. An in-depth sports medicine profile of women college tennis players. *Journal of sport rehabilitation*. 4:79-98, 1995.

92. 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.

93. KRAEMER, W. J., J. S. VOLEK, J. A. BUSH, M. PUTUKIAN, and W. J. SEBASTIANELLI. Hormonal responses to consecutive days of heavy-resistance exercise with or without nutritional supplementation. *J Appl Physiol*. 85:1544-1555., 1998.

94. KRAEMER, W. J., S. J. FLECK, C. M. MARESH, N. A. RATAMESS, S. E. GORDON, K. L. GOETZ, E. A. HARMAN, P. N. FRYKMAN, J. S. VOLEK, S. A. MAZZETTI, A. C. FRY, L. J. MARCHITELLI, and J. F. PATTON. Acute hormonal responses to a single bout of heavy resistance exercise in trained power lifters and untrained men. *Can J Appl Physiol*. 24:524-537., 1999.

95. 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. ETZWEILER, M. PUTUKIAN, and W. J. SEBASTIANELLI. The effects of NCAA Division I intercollegiate competitive tennis match play on recovery of physical performance in women. *Journal of strength and conditioning research*. 14:265-272, 2000.

96. 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.

97. KRAEMER, W. J., A. C. FRY, M. R. RUBIN, T. TRIPLETT-MCBRIDE, S. E. GORDON, L. P. KOZIRIS, J. M. LYNCH, J. S. VOLEK, D. E. MEUFFELS, R. U. NEWTON, and S. J. FLECK. Physiological and performance responses to tournament wrestling. *Med Sci Sports Exerc*. 33:1367-1378., 2001.

98. KRAHENBUHL, G. S., J. HARRIS, J. STERN, D. J. CREWS, and N. HUBALIK. Stress responses and performance in intercollegiate golfers.:, 1999.

99. KRANE, V. and J. WILLIAMS. Performance and somatic anxiety, cognitive anxiety, and confidence changes prior to competition. *Journal of Sport Behavior*. 10:47-56, 1987.

100. KREUZ, L. E., R. M. ROSE, and J. R. JENNINGS. Suppression of plasma testosterone levels and psychological stress. A longitudinal study of young men in Officer Candidate School. *Arch Gen Psychiatry*. 26:479-482., 1972.

101. LAC, G., N. LAC, and A. ROBERT. Steroid assays in saliva: a method to detect plasmatic contaminations. *Arch Int Physiol Biochim Biophys*. 101:257-262., 1993.

102. LAMPSA, M. A. Maximizing distance of the golf drive: an optimal control study. *Journal of dynamic Systems, Measurement , and Control*:362-367, 1975.

103. LANFORD, E. E. Effect of strength training on distance and accuracy in golf, Univ. of Oregon, Eugene, Ore1978.

104. LAUBACH, L. L. Comparative muscular strength of men and women: a review of

the literature. *Aviat Space Environ Med.* 47:534-542., 1976.

105. LAUDER, D., J. L. MAYHEW, W. KEMMLER, and J. WEINECK. Repetitions to fatigue to predict 1-RM bench press, squat, and deadlift in elite European power lifters..

106. LENNON, H. M. Physiological profiling and physical conditioning for elite golfers. In *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf.* St Andrews, Scotland: Human Kinetics,, 1998.

107. LEYMARIE, P., M. ROGER, M. CASTANIER, and R. SCHOLLER. Circadian variations of plasma testosterone and estrogens in normal men. A study by frequent sampling. *J Steroid Biochem.* 5:167-171., 1974.

108. LOWE, B. and L. H. FAIRWEATHER. Centrifugal force and the planar golf swing. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* A. J. Cochran and M. R. Farrally (Eds.) London: E & FN Spon, 1994, pp. 59-64.

109. 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. Eastern Washington University, Eugene, OR, 1997.

110. LYTTLE, A. D., G. J. WILSON, and K. J. OSTROWSKI. Enhancing performance: maximal power versus combined weights and plyometrics training. *Journal of strength and conditioning research.* 10:173-179, 1996.

111. MAGNUSSON, G. Golf: Exercise for Fitness and Health. In *Science and Golf III, Proceedings of the 1998 World Scientific Congress of Golf.* St Andrews, Scotland: Human Kinetics, pp. 51-57, 1998.

112. MANN, R. and F. GRIFFIN. *Swing Like a Pro.* New York: Bantam Doubleday Dell Publishing Group, Inc., 1998

113. MARTENS, R., R. VEALEY, and D. BURTON. *Competitive Anxiety in Sport.* Champaign, IL: Human Kinetics, 1990

114. MASON, D. R. Effects of different weight golf shafts on clubhead velocity prior to contact with the ball. *Univ. of Oregon, Eugene, Ore.* 2, 1973.

115. MASON, J. W. A review of psychoendocrine research on the sympathetic-adrenal medullary system. *Psychosom Med.* 30:Suppl:631-653., 1968.

116. MATHER, J. S. B., M. J. SMITH, S. JOWETT, K. A. H. GIBSON, and D. MOYNIHAN. Application of a photogrammetric technique to golf club evaluation. *Sports engineering.* 3:37-47, 2000.

117. MAYNARD, I. W. and B. L. HOWE. Interrelations of trait and state anxiety with game performance of rugby players. *Perceptual and Motor Skills.* 64:599-602, 1987.

118. MAZUR, A. A biosocial model of status in face-to-face primate groups. *Social Forces.* 64:377-402, 1985.

119. MAZUR, A., A. BOOTH, and J. M. DABBS. Testosterone and chess competition. *Social Psychology Quarterly.* 55:70-77, 1992.

120. MAZZETTI, S. A., W. J. KRAEMER, J. S. VOLEK, N. D. DUNCAN, N. A. RATAMESS, A. L. GOMEZ, R. U. NEWTON, K. HAKKINEN, and S. J. FLECK. The influence of direct supervision of resistance training on strength performance. *Med Sci Sports*

Exerc. 32:1175-1184., 2000.

121. MCAULEY, E. State anxiety: antecedent or result of sport performance. *Journal of sport behavior*. 8:71-77, 1985.
122. MCBRIDE, D. K. Provision of enabling technology in professional sports. *Perceptual and motor skills*. 90:1219-1231, 2000.
123. MCCARROL, J. R. and T. J. GIOE. Professional Golfers and the Price They Pay. *Physiology and Sports Medicine*. 10:64, 1982.
124. MCCARROLL, J. R., A. C. RETTIG, and K. D. SHELBOURNE. Injuries in the amateur golfer. *Physician and sportsmedicine*. 18:122-126, 1990.
125. MCEVOY, K. P. and R. U. NEWTON. Baseball throwing speed and base running speed: the effects of ballistic resistance training. *Journal of strength and conditioning research*. 12:216-221, 1998.
126. MCKAY, J. M., S. E. SELIG, J. S. CARLSON, and T. MORRIS. Psychophysiological stress in elite golfers during practice and competition. *Aust J Sci Med Sport*. 29:55-61., 1997.
127. MCLAUGHLIN, P. A. and R. J. BEST. Three-dimensional kinematic analysis of the golf swing. In *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf*. London: E & FN Spon,, 1994.
128. MCTEIGUE, M., S. R. LAMB, R. MOTTRAM, and F. PRIOZZOLO. Spine and Hip Motion Analysis during the golf swing. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf*. M. R. Farrally and A. J. Cochran (Eds.) London: E & FN Spon, 1994, pp. 50-58.
129. MILBURN, P. D. Summation of segmental velocities in the golf swing. *Med Sci Sports Exerc*. 14:60-64, 1982.
130. 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.
131. MOYNES, D. R., J. PERRY, D. J. ANTONELLI, and F. W. JOBE. Electromyography and motion analysis of the upper extremity in sports. *Phys Ther*. 66:1905-1911., 1986.
132. MURRAY, P. M. and W. P. COONEY. Golf-induced injuries of the wrist. *Clin Sports Med*. 15:85-109., 1996.
133. NATIONAL SPORTING GOODS, A. Exercise walking remains America's favorite participant sport, according to NSGA study. *NSGA news*. 14:4, 2001.
134. NAVARRO, M. A., J. M. GOMEZ, C. M. VILLABONA, and R. BONNIN. Salivary testosterone: a good measure to reflect free testosterone. *Arch Intern Med*. 147:1189., 1987.
135. NEAL, R. J., B. ABERNETHY, and R. J. BURGESS-LIMERICK. 3D Kinematics and kinetics of the golf swing. *International Journal of Biomechanics*. 1:221-232, 1985.
136. NEAL, R. J., B. ABERNETHY, M. J. MORAN, and A. W. PARKER. Expert-novice differences in muscle activity during the golf swing. In *Science and Golf, Proceedings of the First World Scientific Congress of Golf*. St Andrews, Scotland:

E. & F. N. Spon,, 1990.

137. NESBIT, S. M., J.S. COLE, K. A. THARTZELL, OGLESBY, and RADICH. Dynamic model and computer simulation of a golf swing. In *Science and Golf II*. St Andrews, Scotland: E & FN Spon, pp. 66-71, 1994.
138. NEWTON, R. U. and K. P. MCEVOY. Baseball throwing velocity: a comparison of medicine ball training and weight training. *Journal of strength and conditioning research*. 8:198-203, 1994.
139. NILSSON, P. M., L. MOLLER, and K. SOLSTAD. Adverse effects of psychosocial stress on gonadal function and insulin levels in middle-aged males. *J Intern Med.* 237:479-486., 1995.
140. ORLICK, T. and J. PARTINGTON. Mental links to excellence. *The Sports Psychologist*. 2:105-130, 1988.
141. OVER, R., AND THOMAS, P. Age and skilled psychomotor performance: A comparison of younger and older golfers. *International Journal of Aging and Human Development*. 41:1-12, 1995.
142. PARCHMAN, L. L. Cinematographical and mechanical analysis of the golf swing of female golfers. *University Microfilms, Ann Arbor*. 1, 1970.
143. PASSELERGUE, P., A. ROBERT, and G. LAC. Salivary cortisol and testosterone variations during an official and a simulated weight-lifting competition. *Int J Sports Med.* 16:298-303., 1995.
144. PASSELERGUE, P. and G. LAC. Saliva cortisol, testosterone and T/C ratio variations during a wrestling competition and during the post-competitive recovery period. *Int J Sports Med.* 20:109-113., 1999.
145. PELZ, D. *Dave Pelz's Putting Bible*. New York: Doubleday, 2000
146. PFISTER, H. P. and G. MAFFESONI. Stress induced activation of the endogenous opioid systems. In: *Stress Effects on Central and Peripheral Systems: A Primer*. P. H. Pfister (Ed.) Brisbane, Australia: Australian Academic Press, 1992.
147. PFISTER, H. P. and J. L. MUIR. Arousal and Stress: A Consideration of Theoretical Approaches. In: *Stress Effects on Central and Peripheral Systems: A Primer*. P. H. Pfister (Ed.) Brisbane, Australia: Australian Academic Press, 1992.
148. PINK, M., F. W. JOBE, and J. PERRY. Electromyographic analysis of the shoulder during the golf swing. *Am J Sports Med.* 18:137-140., 1990.
149. PINK, M., J. PERRY, and F. W. JOBE. Electromyographic analysis of the trunk in golfers. *Am J Sports Med.* 21:385-388., 1993.
150. 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.
151. POMPA, B. Shaft tip flex & kick point affect recovery speed. *Golf clubmaker.* 16:11-12, 1993.
152. PORT, K. Serum and saliva cortisol responses and blood lactate accumulation during incremental exercise testing. *Int J Sports Med.* 12:490-494., 1991.
153. RAGLIN, J. S. Anxiety and sport performance. *Exerc Sport Sci Rev.* 20:243-274, 1992.
154. REDDY, A. P. Relationships among technical skills and physical fitness of amateur golf players in India. In *Science and Golf, Proceedings of the First World*

Scientific Congress of Golf. St Andrews, Scotland: E. & F. N. Spon, pp. 64-69, 1990.

155. RIAD-FAHMY, D., G. F. READ, R. F. WALKER, and K. GRIFFITHS. Steroids in saliva for assessing endocrine function. *Endocr Rev.* 3:367-395., 1982.

156. 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 & FN Spon, 1990, pp. 153-158.

157. RICHARDS, J., M. FARRELL, and J. KENT. Weight transfer patterns during the golf swing. *Research Quarterly.* 56:361-365, 1985.

158. 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 & FN Spon, 1994, pp. 84-91.

159. ROSE, R. M., L. E. KREUZ, J. W. HOLADAY, K. J. SULAK, and C. E. JOHNSON. Diurnal variation of plasma testosterone and cortisol. *J Endocrinol.* 54:177-178., 1972.

160. SALE, D. G. Neural adaptation to resistance training. *Med Sci Sports Exerc.* 20:S135-145., 1988.

161. SHERMAN, C. A. and C. F. FINCH. Preventing injuries to competitive and recreational adult golfers: what is the evidence? *J Sci Med Sport.* 3:65-78., 2000.

162. SIEGEL, R. A., J. WEIDENFELD, S. FELDMAN, N. CONFORTI, and I. CHOWERS. Neural pathways mediating basal and stress-induced secretion of luteinizing hormone, follicle-stimulating hormone, and testosterone in the rat. *Endocrinology.* 108:2302-2307., 1981.

163. SMITH, A. M., S. A. MALO, E. R. LASKOWSKI, M. SABICK, W. P. COONEY, 3RD, S. B. FINNIE, D. J. CREWS, J. J. EISCHEN, I. D. HAY, N. J. DETLING, and K. KAUFMAN. A multidisciplinary study of the 'yips' phenomenon in golf: An exploratory analysis. *Sports Med.* 30:423-437., 2000.

164. SPRATT, D. I., L. S. O'DEA, D. SCHOENFELD, J. BUTLER, P. N. RAO, and W. F. CROWLEY, JR. Neuroendocrine-gonadal axis in men: frequent sampling of LH, FSH, and testosterone. *Am J Physiol.* 254:E658-666., 1988.

165. SPRIGINGS, E. J. and R. J. NEAL. An insight into the importance of wrist torque in driving the golf ball: a simulation study. *Journal of applied biomechanics.* 16:356-366, 2000.

166. STEIN-BEHRENS, B. A. and R. M. SAPOLSKY. Stress, glucocorticoids, and aging. *Aging (Milano).* 4:197-210., 1992.

167. 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 and conditioning.* 20:22-31, 1998.

168. 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 Dissertation.* Brigham Young University, Univ. of Oregon, Eugene, Ore1978.

169. SUAY, F., A. SALVADOR, E. GONZALEZ-BONO, C. SANCHIS, M. MARTINEZ, S. MARTINEZ-SANCHIS, V. M. SIMON, and J. B. MONTORO. Effects of competition and its outcome on serum testosterone, cortisol and prolactin. *Psychoneuroendocrinology*. 24:551-566., 1999.

170. TAYLOR, J. Predicting athletic performance with self-confidence and somatic and cognitive anxiety as a function of motor and physiological requirements in six sports. *Journal of Personality*. 55:139-153, 1987.

171. THERIAULT, G., E. LACOSTE, and M. P. GABOURY. Golf injury characteristics: a survey from 528 golfers. *Med Sci Sports Exerc*. 28:565, 1996.

172. THERIAULT, G. and P. LACHANCE. Golf injuries. An overview. *Sports Med*. 26:43-57., 1998.

173. THOMAS, J. R. and J. K. NELSON. *Research Methods in Physical Activity*. Champaign, IL: Human Kinetics, 1996

174. TORTORA, G. J. and S. R. GRABOWKI. *Principles of Anatomy and Physiology*. 9th ed. New York: John Wiley & Sons, Inc., 2000

175. UMEDA, T., R. HIRAMATSU, T. IWAOKA, T. SHIMADA, F. MIURA, and T. SATO. Use of saliva for monitoring unbound free cortisol levels in serum. *Clin Chim Acta*. 110:245-253., 1981.

176. URHAUSEN, A., T. KULLMER, and W. KINDERMANN. A 7-week follow-up study of the behaviour of testosterone and cortisol during the competition period in rowers. *Eur J Appl Physiol Occup Physiol*. 56:528-533, 1987.

177. URHAUSEN, A., H. GABRIEL, and W. KINDERMANN. Blood hormones as markers of training stress and overtraining. *Sports Med*. 20:251-276., 1995.

178. VAERNES, R., H. URSIN, A. DARRAGH, and R. LAMBE. Endocrine response patterns and psychological correlates. *J Psychosom Res*. 26:123-131, 1982.

179. 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.

180. VELDHUIS, J. D., J. C. KING, R. J. URBAN, A. D. ROGOL, S. A. EVANS, S. A. KOLF, and M. L. JOHNSON. Operating characteristics of the male hypothalomo-pituitary-gonadal axis: pulsatile release of testoserone and follicle-stimulating hormone and their temporal coupling with lutenizing hormone. *Journal of Clinical Endocrinology and Metabolism*. 65:929-941, 1993.

181. VINING, R. F., R. A. MCGINLEY, J. J. MAKSVYTIS, and K. Y. HO. Salivary cortisol: a better measure of adrenal cortical function than serum cortisol. *Ann Clin Biochem*. 20:329-335., 1983.

182. VINING, R. F., R. A. MCGINLEY, and R. G. SYMONS. Hormones in saliva: mode of entry and consequent implications for clinical interpretation. *Clin Chem*. 29:1752-1756., 1983.

183. VITTEK, J., D. G. L'HOMMEDIEU, G. G. GORDON, S. C. RAPPAPORT, and A. L. SOUTHREN. Direct radioimmunoassay (RIA) of salivary testosterone: correlation with free and total serum testosterone. *Life Sci*. 37:711-716., 1985.

184. WALKER, R. F., B. G. JOYCE, and J. DYAS. Monitoring changes in normal adrenal

activity. In: *Immunoassays of Steroids in Saliva.* G. F. Read, R.-F. D., and R. F. Walker (Eds.) Cardiff: Alpha Omega, 1984, pp. 308-316.

185. WALLACE, E. S., D. GRAHAM, and E. W. BLEAKLEY. Foot-to-ground pressure patterns during the golf drive: a case study involving a low handicap player and a high handicap player. In: *Science and Golf, Proceedings of the First World Scientific Congress of Golf.* A. J. Cochran (Ed.) St Andrews, Scotland: E. & F. N. Spon, 1990.
186. WALLACE, E. S., P. N. GRIMSHAW, and R. L. ASHFORD. Discrete pressure profiles of the feet and weight transfer patterns during the golf swing. In: *Science and Golf II: Proceedings of the Second World Scientific Congress of Golf.* A. J. Cochran and M. R. Farrally (Eds.) London: E & FN Spon, 1994, pp. 26-32.
187. WALTON, J. S. Close-range cine-photogrammetry: a generalized technique for quantifying gross human motion. Pennsylvania State University, University Park, PA, 1981.
188. 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.
189. WEATHERS, E. Tiger's supersonic stinger. *Golf Digest. Apr.* 51:84-88, 2000.
190. WENZEL, D. Weight Training and Its Effect on the Golf Drive. *Unpublished Masters Thesis*. University of North Dakota1967.
191. WERNERMAN, J., D. BOTTA, F. HAMMARQVIST, S. THUNELL, A. VON DER DECKEN, and E. VINNARS. Stress hormones given to healthy volunteers alter the concentration and configuration of ribosomes in skeletal muscle, reflecting changes in protein synthesis. *Clin Sci (Colch).* 77:611-616., 1989.
192. WERNERMAN, J., F. HAMMARQVIST, D. BOTTA, and E. VINARS. Stress hormones alter the pattern of free amino acids in human skeletal muscle. *Clin Physiol.* 13:309-319., 1993.
193. WESTCOTT, W. L., F. DOLAN, and T. CAVICCHI. Golf and strength training are compatible activities. *Strength and conditioning.* 18:54-56, 1996.
194. 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 management.* 13:39-41, 1997.
195. WHITTAKER, A. R. A study of the dynamics of the golf club. *Sports engineering.* 1:115-124, 1998.
196. WILLIAMS, K. R. and P. R. CAVANAGH. The mechanics of foot action during the golf swing and implications for shoe design. *Medicine Science Sports and Exercise.* 15:247-255, 1983.
197. WILMORE, J. H. Alterations in strength, body composition and anthropometric measurements consequent to a 10-week weight training program. *Med Sci Sports.* 6:133-138., 1974.
198. WILMORE, J. H. and D. L. COSTILL. *Physiology of Sport and Exercise.* Champaign, IL: Human Kinetics, 1999
199. WILSON, G., R. NEWTON, A. MURPHY, and B. HUMPHRIES. The Optimal Training Load for the Development of Dynamic Athletic Performance. *Medicine and*

Science in Sports and Exercise. 25:1279-1286, 1993.

200. WIREN, G. Human Factors influencing the golf drive for distance. *Doctoral Dissertation*. University of Oregon1968.

201. WIREN, G. Laws, principles and preference--a teaching models. In: *Science and Golf, Proceedings of the First World Scientific Congress of Golf.* A. J. Cochran (Ed.) London: E. & F. N. Spon, 1990, pp. 3-13.

202. WOLOSKI, B. M., E. M. SMITH, W. J. MEYER, 3RD, G. M. FULLER, and J. E. BLALOCK. Corticotropin-releasing activity of monokines. *Science*. 230:1035-1037., 1985.

203. YAN LAN, L. and D. L. GILL. The relationships among self-efficacy, stress responses, and a cognitive feedback manipulation. *Journal of Sport Psychology*. 6, 1984.

204. ZATSIORSKY, V. M. *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics, 1995

205. ZHANG, J. The correlation among three hand strength measurement methods: hand dynamometer. *Masters Thesis*. Ball State University, School of Physical Education, Muncie, IN, 1996.

Appendix A

INFORMED CONSENT FORM FOR STUDY #1: THE EFFECTS OF RESISTANCE TRAINING ON GOLF PERFORMANCE IN COMPETETITIVE INTERCOLLEGIATE MEN AND WOMEN GOLFERS

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN SUBJECT RESEARCH

Ball State University

"The effects of periodized resistance training on golf performance in Collegiate golfers."

You have been chosen as a potential subject based on your membership on the Ball State Men's and Women's Golf teams. All athletes on the Golf teams are invited to participate. The investigators and coaches give you the strongest commitment that you are under no pressure or coercion to participate in this study. The decision to participate or not will have no influence or prejudice on you in any form and should you choose not to participate, you will be provided with the same resistance training program and coaching time commitment that you would have received should this project never have been performed.

Purpose

The purpose of this study is to examine the effects of strength, power, and flexibility training on competitive men and women golfers.

Procedures

You are fully welcome to decline participation in this study. If you agree to participate, you will be tested on measures of muscle strength and power, joint flexibility and golf performance before, after and during a resistance-training program. There is a requirement for you to attend and complete these testing and training sessions to be involved in this study.

All neuromuscular testing and training will be completed in the Ball State University Biomechanics Laboratory and the University Arena. Golf ball launch condition and putting distance control testing will be completed at MD's Golf Academy, Muncie IN. All subjects will train for 11 weeks using standard resistance training exercises and upper-body plyometric exercises.

Ball State Athletic Weight-room staff will supervise all resistance training. You are normally required to participate in periodized resistance training and upper-body plyometrics, this investigation will simply measure the neuromuscular and golf performance related effects of the training. You will complete the usual warm-up performed prior to commencing their normal resistance training workouts. You will then complete 3 to 6 sets of 3 to 15 repetitions at loads of 50% to 90% of 1 repetition maximum (RM) on several traditional resistance training and upper-body plyometric exercises. One to three minutes of rest will be enforced between sets. Training will be performed three times per week.

Test Protocol: You will be tested before and after 11 weeks of strength, power, and flexibility training.

Golf Ball Launch Conditions: You will hit 30 golf balls with a driver and 30 golf balls with a 5 iron. Golf ball launch data will be collected for each trial with a golf swing and ball launch condition analyzer. Additionally, your swing will be recorded using a digital video camera. A qualitative analyses will be performed using computer software to overlay swing images from different time periods and compare critical swing elements before, during and after training.

Putting distance control test: Subjects will putt 30 balls two different distances (10 feet and 30 feet) to a line perpendicular to the intended direction of the ball. Deviation from the line will be measured for each trial and compared between time points.

Strength testing: You will be tested on rotational trunk power by throwing medicine ball (3 lbs. to 8 lbs.) through a target for maximum distance. Grip strength will be measured using a handgrip dynamometer.

Flexibility: Maximum trunk rotation in both directions and sit and reach maximum flexibility will be measured.

Confidentiality

All data collected will remain confidential. The results from testing will be kept in locked cabinets at Ball State University. Only the Investigator will know which data is associated with which specific athletes.

A random identification number will identify you. Only the Investigator will have access to this code. Your name will not be used in connection with any part of this study nor will the results be shared with any member of your coaching staff without your consent.

Please be aware that should any of the individual project results be used in the development of instructional materials, or for presentations, you will have to approve such use in writing, otherwise the results will be stored at the completion of the project.

Risks

This study will use standard biomechanical and physiological analysis techniques. There is risk of sustaining an injury to a muscle or joint during strength testing and training exercise, however, the risk is no greater than the risk normally associated with the performance of resistance training movements that competitive Golfers use in training. You may also experience muscle soreness 24-48 hours following the protocol. There is no additional risk to the standard risks an individual assumes when playing Golf.

The investigators are very experienced with the testing and training procedures to be used and there are many safeguards to ensure that risk of injury is minimized. During all tests, you will be monitored to ensure that you use the correct lifting technique. You will be required to warm-up thoroughly prior to any testing or training session. Research assistants will be in attendance to "spot" for you during the heavy lifting and help should you get into difficulty. During all testing and training sessions trained personnel will be present to ensure your safety and monitor your training.

Potential Benefits
There is a positive direct benefit of this study to you in that you will learn more about your strength and power in movements that are very specific to your sport and about actual performance of your sport. Also, it is anticipated that your performance will benefit from the training program. You are welcome to contact the Investigator to obtain access to your data. You are welcome to discuss your results with the Investigator.

Injury and Compensation
It is understood that in the unlikely event of physical injury resulting from research procedures, Ball State University, its agents and employees, will assume whatever responsibility is required by law. Emergency medical treatment for injuries of illness is available where the injury or illness is incurred during the course of the study.

Assurance Statement
For one's rights as a research subject, the following persons may be contacted: Ms. Sandra Smith, Coordinator of Research Compliance, Office of Academic Research and Sponsored Programs, Ball State University, Muncie, IN 47306, (765) 285-5070, or Dr. Daniel Goffman, Chairperson of the Institutional Review Board, Dept. of History, Ball State University, Muncie, IN 47306, (765) 285-8700. Please direct questions to Dr. Robert Newton, telephone (765) 285 5139 if you need further information concerning this study. If you decline to participate in this study, none of your data will be chosen for analysis, nor will your capacity for participation in Ball State Athletics be affected.

Authorization
– The investigation and my part in the investigation have been defined and fully explained to me by Dr. Robert Newton, and I understand his explanation. A copy of the procedures of this investigation and a description of any risks and discomforts (e.g., muscle soreness, possible muscle strain), which are encountered during the experiment has been provided to me and has been discussed in detail with me.
– I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
– It has been made very clear to me that I am under no pressure or coercion from the investigators or coaches to participate in this study.
– I understand that I may withdraw from the data collection session at any time should I feel uncomfortable or wish to stop.
– I understand that I am free to deny any answers to specific items or questions in

interviews or questionnaires.

– I understand that any data or answers to questions will remain confidential with regard to my identity.

– I understand that in the unlikely event of a physical injury resulting from such procedures, Ball State University, its agents and employees, will assume whatever responsibility required by law. Emergency medical treatment for injuries or illness is available if the injury or illness is incurred in the course of this study.

– I certify that to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

– I FURTHER UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TERMINATE MY PARTICIPATION AT ANY TIME WITHOUT PENALTY OR LOSS OF BENEFITS TO WHICH SUBJECTS/ATHLETES ARE ENTITLED.

I have read the above and understand the discomforts, inconvenience, and risk of this study.

I___________________________________, agree to participate in this research entitled "The effects of periodized resistance training on golf performance in collegiate golfers". I understand that I may later refuse to participate, and that I may withdraw from this study at any time with no consequences to my standing as an athlete. I have received a copy of this consent form for my own records and I understand that no one will know my individual results from this study.

_________________________________   ________________

Participant's Signature   Date

I___________________________________,(consent / do not consent) to have the results of this study provided to (Mike Fleck / Shelly Sanders), Head Coach by the investigators.

_________________________________   ________________

Participant's Signature   Date

Principal Investigator:
Dr. Robert U. Newton
Human Performance Laboratory
Ball State University
Muncie, IN 47306
(765) 285-5139

Co-Investigator:
Brandon Doan
Human Performance Laboratory
Ball State University
Muncie, IN 47306
(765) 285-5178

Appendix B

INFORMED CONSENT FORM FOR STUDY #2: PHYSIOLOGICAL STRESS RESPONSE DURING COMPETITIVE GOLF

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN SUBJECT RESEARCH

Ball State University

"Physiological Stress Response During Competitive Golf."

You have been chosen as a potential subject based on your membership on the Ball State Men's or Women's Golf teams. All athletes on the Golf teams are invited to participate. The investigators and coaches give you the strongest commitment that you are under no pressure or coercion to participate in this study. The decision to participate or not will have no influence or prejudice on you in any form and should you choose not to participate, you will be provided with the same resistance training program and coaching time commitment that you would have received should this project never have been performed.

Purpose

You are being asked to participate in a study to examine the relationship between golf competitive environment, performance and physiological stress response. This study is being conducted to gain information on the physiological stress response of a golfer in competition.

Rationale for conducting study

Increased secretion of the catabolic hormone Cortisol has been correlated to increases in physical and psychological stress, particularly negative mood states. Decreased secretion of the anabolic hormone Testosterone has been correlated to increased physical activity and decreased performance in competition. The interaction of these two hormones with individual performance on each hole and overall performance will be valuable information for golfers and sport psychologists. Additionally, the ratio of Testosterone to Cortisol secretion is an important indicator of energetic state. Collegiate golfers may be in a catabolic state for an excessive period of time during a 36-hole competition, which has implications for pre and post-round nutrition, immune response and overall health of the competitive golfer. Finally, performance anxiety may be correlated with increased Cortisol secretion, decreased Testosterone secretion, and performance. Some golfers may be too aroused before the round, while others are not aroused enough for optimal performance.

Procedures

You are fully welcome to decline participation in this study. If you agree to participate, there is a requirement for you to collect saliva samples after each hole during the first 36 holes (18 holes for the women) of your home golf tournament. You will remove the cotton wool swab from the salivette and chew on it for 45 seconds while recording the time of sample. 36 salivettes will be pre-labeled and stored in a small Styrofoam cooler attached to the your golf bag. You will be asked not to consume caffeine on the day of testing, however, there are no other dietary restrictions. Additionally, subjects will complete a standardized competitive state anxiety questionnaire prior to performance. The questionnaire will only take approximately five minutes to complete.

Baseline saliva samples will be collected on a different day. You will collect your own samples and participate in normal daily activities, except for strenuous exercise. You will report to the Human Performance Lab in the morning for instructions and a collection kit and will return samples at the end of the day. Timing of baseline samplings will be dependent on timing of samplings during competition. You will be asked to replicate dietary intake from first day of collection. Saliva samples will be analyzed in the laboratory at a later date to compare Cortisol and Testosterone concentration to baseline conditions and performance on the previous and following holes.

Confidentiality

All data collected will remain confidential. The results from testing will be kept in locked cabinets at Ball State University. Only the Investigator will know which data is associated with which specific athletes.

A random identification number will identify you. Only the Investigator will have access to this code. Your name will not be used in connection with any part of this study nor will the results be shared with any member of your coaching staff without your consent.

Please be aware that should any of the individual project results be used in the development of instruction materials, or for presentations, you will have to approve such use in writing, otherwise the results will be stored at the completion of the project.

Risks

There is no additional risk to the standard risks an individual assumes when competing in golf other than the unlikely possibility of choking on or swallowing one of the cotton wool swabs.

Potential Benefits

There is a positive direct benefit of this study to you in that you will learn more about their stress hormone response during competition. You are welcome to contact the Investigator to obtain access to your data. You are welcome to discuss your results with the Investigator.

Injury and Compensation

It is understood that in the unlikely event of physical injury resulting from research procedures, Ball State University, its agents and employees, will assume whatever responsibility is required by law. Emergency medical treatment for injuries or illness is available where the injury or illness is incurred during the course of the study.

Assurance Statement

For one's rights as a research subject, the following persons may be contacted: Ms.

Sandra Smith, Coordinator of Research Compliance, Office of Academic Research and Sponsored Programs, Ball State University, Muncie, IN 47306, (765) 285-5070, or Dr. Daniel Goffman, Chairperson of the Institutional Review Board, Dept. of History, Ball State University, Muncie, IN 47306, (765) 285-8700. Please direct questions to Dr. Robert Newton, telephone (765) 285-5139 if you need further information concerning this study. If you decline to participate in this study, none of your data will be chosen for analysis, nor will your capacity for participation in Ball State Athletics be affected.

Authorization

– The investigation and my part in the investigation have been defined and fully explained to me by Mr. Brandon Doan, and I understand his explanation. A copy of the procedures of this investigation and a description of any risks and discomforts (e.g., muscle soreness, possible muscle strain), which are encountered during the experiment has been provided to me and has been discussed in detail with me.

– I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.

– It has been made very clear to me that I am under no pressure or coercion from the investigators or coaches to participate in this study.

– I understand that I may withdraw from the data collection session at any time should I feel uncomfortable or wish to stop.

– I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.

– I understand that any data or answers to questions will remain confidential with regard to my identity.

– I understand that in the unlikely event of a physical injury resulting from such procedures, Ball State University, its agents and employees, will assume whatever responsibility required by law. Emergency medical treatment for injuries or illness is available if the injury or illness is incurred in the course of this study.

– I certify that to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

– I FURTHER UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TERMINATE MY PARTICIPATION AT ANY TIME WITHOUT PENALTY OR LOSS OF BENEFITS TO WHICH SUBJECTS/ATHLETES ARE ENTITLED.

I have read the above and understand the discomforts, inconvenience, and risk of this study.

I__________________________________, agree to participate in this research entitled "Physiological Stress Response During Competitive Golf". I understand that I may later refuse to participate, and that I may withdraw from this study at any time with no consequences to my standing as an athlete. I have received a copy of this consent form for my own records and I understand that no one will know my individual results from this study.

I__________________________________,(consent / do not consent) to have the results of this study provided to (Mike Fleck / Shelly Sanders), Head Coach by the investigators.

________________________________ _______________

Participant's Signature Date

________________________________ _______________

Investigator's Signature Date

Principal Investigator:
Dr. Robert U. Newton
Human Performance Laboratory
Ball State University
Muncie, IN 47306
(765) 285-5139

Co-Investigator:
Brandon Doan
Human Performance Laboratory
Ball State University
Muncie, IN 47306
(765) 285-5178

Appendix C

COMPETITIVE STATE ANXIETY INVENTORY-2 (CSAI-2)

Illinois Self-Evaluation Questionnaire

Name: ______________________ Sex: M F Date: __________

Directions: A number of statements that athletes have used to describe their feelings before competition are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate *how you feel right now*—at this moment. There are no right or wrong answers. Do *not* spend too much time on any one statement, but choose the answer which describes your feelings *right now*.

	Not At All	**Somewhat**	**Moderately So**	**Very Much So**
1. I am concerned about this competition	1	2	3	4
2. I feel nervous	1	2	3	4
3. I feel at ease	1	2	3	4
4. I have self-doubts	1	2	3	4
5. I feel jittery	1	2	3	4
6. I feel comfortable	1	2	3	4
7. I am concerned that I may not do as well in this competition as I could	1	2	3	4
8. My body feels tense	1	2	3	4
9. I feel self-confident	1	2	3	4
10. I am concerned about losing	1	2	3	4
11. I feel tense in my stomach	1	2	3	4
12. I feel secure	1	2	3	4
13. I am concerned about choking under pressure	1	2	3	4
14. My body feels relaxed	1	2	3	4
15. I'm confident I can meet the challenge	1	2	3	4
16. I'm concerned about performing poorly	1	2	3	4
17. My heart is racing	1	2	3	4
18. I'm confident about performing well	1	2	3	4
19. I'm concerned about reaching my goal	1	2	3	4
20. I feel my stomach sinking	1	2	3	4
21. I feel mentally relaxed	1	2	3	4
22. I'm concerned that others will be disappointed with my performance	1	2	3	4
23. My hands are clammy	1	2	3	4
24. I'm confident because I mentally picture myself reaching my goal	1	2	3	4
25. I'm concerned I won't be able to concentrate	1	2	3	4
26. My body feels tight	1	2	3	4
27. I'm confident of coming through under pressure	1	2	3	4

Appendix D

SALIVA COLLECTION, FATIGUE SURVEY, AND FOOD/BEVERAGE CONSUMPTION FORM

1. Remove cotton swab from each salivette (in numerical order) at specified time and **LIGHTLY CHEW** for **45 seconds**. *(If you have trouble producing saliva, chew sugarless gum)*
2. Carefully **replace** cotton swab into salivette and replace salivette into cooler.
3. **Record actual time** of sample in hours and minutes (e.g. 3:30).
4. Use the scale below **to rate your fatigue level after each sample**. Enter one number that best describes your current mental and physical fatigue level after each hole. MF = mental fatigue, PF = physical fatigue.

1	2	3	4	5	6	7	8	9	10
Completely Exhausted									Maximum energy level

Sample	Time	Actual Time	Food/Drink (other than water)	MF	PF	Sample	Time	Actual Time	Food/Drink (other than water)	PF	MF
Pre						**19**					
1						**20**					
2						**21**					
3						**22**					
4						**23**					
5						**24**					
6						**25**					
7						**26**					
8						**27**					
9						**28**					
10						**29**					
11						**30**					
12						**31**					
13						**32**					
14						**33**					
15						**34**					
16						**35**					
17						**36**					
18											

**drink as much water as you need when you need it*

RESTRICTIONS:

****no caffeine** on day of testing**

****no alcohol** the night before or day of testing*

****no sexual activity** the day of testing*

****no food or drink for five minutes prior to sample***

BASELINE RESTRICTIONS ONLY

****No major examinations** or papers due that day or following day if possible*